# A GENERAL HYBRID MODEL FOR SYSTEM EFFECTIVENESS EVALUATIONS

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# A GENERAL HYBRID MODEL FOR SYSTEM EFFECTIVENESS EVALUATIONS

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# PREFACE

This study is directed at the development of a general technique for evaluating the effectiveness of alternative system configurations. The proposed technique utilizes a multidimensional approach to the evaluation of the merit of a given configuration.

The static system elements are ranked and weighted according to their importance to the mission accomplishment. These parameters are then combined mathematically on the lowest possible design level.

The dynamic system elements are evaluated through the use of a multipurpose simulation routine. The simulation model is based on the evaluation of the operational state of the various components during each phase of the mission.

The hybrid programming approach was taken in order to provide for increased flexibility in the system evaluation process. The increased flexibility was desired in order to meet the needs of a varied user group.

This thesis is the culmination of a Ph.D. program, which was undertaken with the support of the National Aeronautics and Space Administration. The opportunity provided by this support is greatly appreciated.

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# CHAPTER I

## PROBLEM DEFINITION

### Introduction

Since the beginning of his existence, man has continually attempted to extend his control over the factors which make up his environment. The early attempts were limited in both their scope and duration, this limitation being due to the limited resources of the single individual. It became clear that if man was to obtain larger and more complex goals, he must join with others. The united group provided the resources and talent to seek and obtain the more complex goal. However, resources and talent alone are limited in the extent to which they can contribute to the accomplishment of objectives. An additional element is needed to bring the various systems elements into a successfully operating system. This additional element is planning for the organization of the various system elements. As the goals increase in size, the task of planning for the integration of the various system elements and resources becomes increasingly important and also becomes increasingly complex.

As Barnard pointed out in his discussion of cooperation in relation to task accomplishment:

> The work to be done is complex in practice, power being requisite at one time, speed at another, continuity of effort at another, and so on (1)

This statement points up the problem facing the systems planner, that is, how best to utilize the limited resources available to him in order to achieve the most effective result.

Prior to recent history, the size and complexity of man's undertakings were for the most part extremely limited. To be sure there were such massive undertakings as the Great Wall of China and the Pyramids, but the number of such large scale undertakings were small indeed. However, in the years following World War II, the size and complexity of systems has grown at a tremendous rate. An example of this growth in size and complexity can be seen in Figure 1. Figure 1 illustrates the growth rate in the size, cost and complexity of fighter aircraft. One of the prime causes for this tremendous increase in size and cost is the addition of functions to the basic goal of the fighter mission. The complicated electronic systems and the extensive weapons control systems have contributed greatly to the increased cost and weight (2). The fighter aircraft is but one example of the increasing complexity facing the systems planner in this day of ever increasing technology. The program manager must determine the system effectiveness in light of complex mission goals and resource limitations.

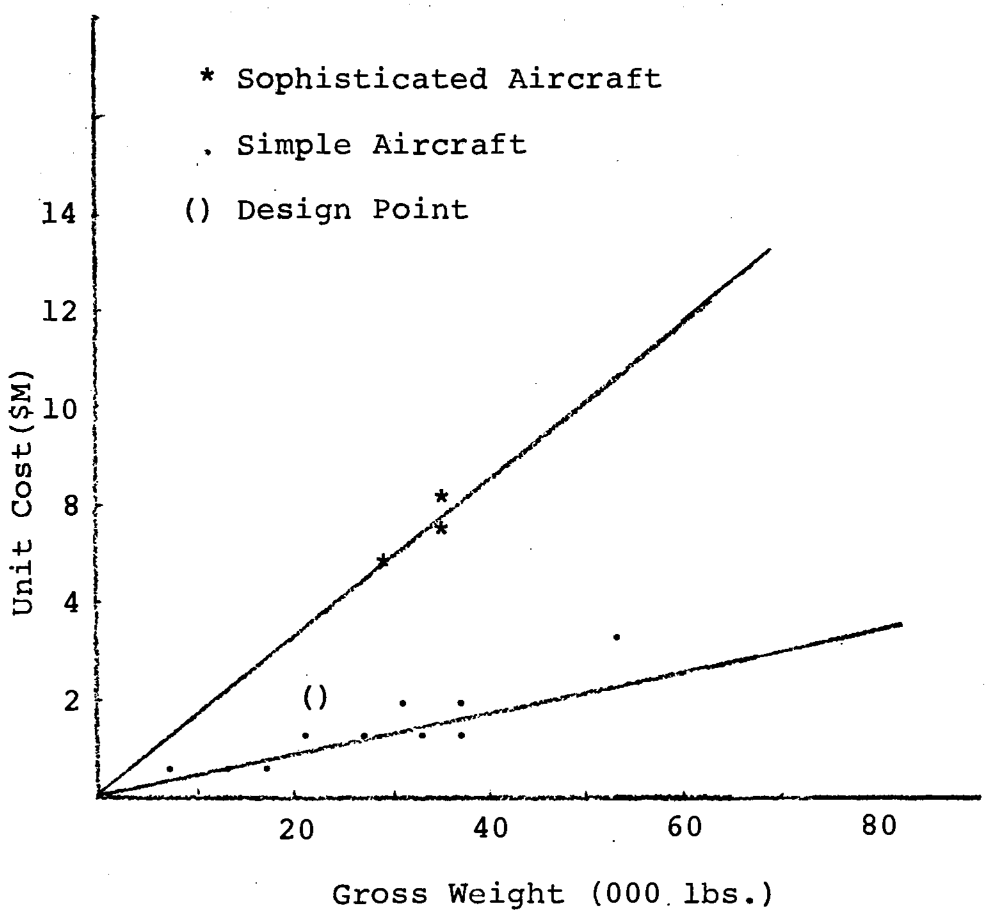


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Figure 1. Unit Cost vs. Gross Weight for Fighter Aircraft

In addition to the pressures exerted by the increasing complexity of today's mission goals, the systems manager is also being faced with increasing pressure from the forces of the external environment. Barnard also served to point out the relationship which exists between an organization and its environment. Barnard points out that:

> Purpose itself has no meaning, however, except in an environment. It can also be defined in terms of an environment (1).

The purpose or goal must be structured and defined within the bounds established by the elements of system environment. The external environmental pressure may come from stockholders, congressional groups, action groups, or any number of similar groups. The pressure exerted by these factions may directly or indirectly effect the development, goals, and success of a project.

During a series of Congressional hearings on the increasing cost of defense systems numerous public and private elements testified as to the causes of the tremendous cost increases. The most commonly mentioned source for the blame was:

> The MOD-tyranny of system analyses gone berserk, the mixed bag of think-tanks (outside, in home, university), mountainous tons of computer paper studies, the massed array of engineers and scientists caught in the trap of deliberately contrived adversary relationships (3)

Oddly enough, the same individuals who point the blame at the system analyst fail to provide any alternative for the control of the complex array of system components.

Congressmen and various action groups continually demand that the program manager justify the system design with respect to such factors as cost and environmental quality. Additionally, these groups are themselves continually performing studies to evaluate the effect of the major public and private systems. It would appear that even with all of its potential weaknesses the system analysis approach to project planning and control provides the most feasible alternative presently available to the project manager.

Compounding the problem facing the project manager of today is the increasing number of projects which have either failed to meet their mission performance goals or have experienced cost overruns. Large project failures such as the F-111, the C5A and the Mark 48 Torpedo have established an air of hostility toward all such large projects.

The F-111 was to be a general purpose fighter bomber capable of fulfilling the needs of all the various services. Complexity on top of complexity was added to the basic airframe and the weapons and electronic systems. The result was an aircraft that not only failed to meet the operational needs of any of the services, but also which failed to function within the performance limits established by the designers.

The C5A serves to illustrate the problems of design error and lack of proper system planning. The initial cost estimate for the C5A was set at a maximum of $2.2 billion, however, over a five year period the cost of these aircraft had increased to $3.7 billion. This increase was in spite of the fact that the number of planes to be purchased under the contract had been reduced from 115 to 81. One of the major elements contributing to the tremendous cost overrun associated with the C5A was that neither Lockheed nor the military properly predicted the severe technical problems that would plague the C5A design (4).

The Mark 48 Torpedo is another example of a complex system which, even with a considerable cost overrun, has repeatedly failed to meet its operational design requirements. It now appears quite possible that this project may be cancelled even before the first operational unit is produced. Again, the problems lie in the complexity of the basic mission requirements and the corresponding complexity in the unit design.

The growth of complex weapons, space, and industrial systems has resulted in a need for a more direct method for evaluation and control of these systems. The various techniques of system analysis and engineering are an attempt at the development of approaches which are adequate to the problem at hand. These techniques provide a new way of viewing the complex system, that is, a view of an integrated system of interfacing elements. This view provides the basis on which such techniques as project management may be applied.

The question of the potential effectiveness of any complex system is an area in which the philosophy of systems analysis may readily be applied. The use of such a unified effectiveness approach will provide for a more realistic evaluation of the interaction of the various system elements.

## The Nature of Systems Effectiveness

The end measure of the effectiveness of any system lies in the degree to which that system is successful in accomplishing its set of objectives. Effectiveness in this sense is an after the fact measure of the performance. While a system may be successful in accomplishing the mission for which it was designed, if this accomplishment is at a cost overrun of 100%, the question of accomplishment may be secondary to that of cost.

The overall concept of systems effectiveness is not a one time affair but rather must be applied to various degrees and to various levels throughout the entire duration of the program. The Navy considers the concept of systems effectiveness to be the basic element around which all of their projects are built. This promotes the view of a systems approach to program control. The Navy also has instituted a series of courses on System Effectiveness Engineering. The introduction to these courses is as follows:

> In the era of complex combinations of men and machines, system effectiveness, and its fiscal corollary, cost effectiveness, constitute the most important considerations in the selection, development and operation of modern weapons systems. The problem we face is to optimize, as best we can, the utilization of our natural resources: men, material, facilities and time (5).

The content of these courses considers the concept of effectiveness engineering as it is applied to all phases of project development, as seen in Figure 2. However, there exist two phases of the project in which the system effectiveness concept becomes of greatest importance.

In the early preliminary design phase, the project manager is faced with the problem of evaluating alternative designs on the basis of limited information. The decisions made at this point in time are of critical importance due to the fact that the early design decisions will have a direct impact on all following program activities. Changes made at this early point in time cost little in comparison to changes made on a completed hardware element.

Of equal importance is the evaluation of the effectiveness of the system in its operational phase. The level of evaluation done at this point is determined, in large measure, by the type of system involved. If the system is of a one time utilization type and no more are to be constructed, then little evaluation may be performed. However, if the system is to be utilized over an extended period of time or if there are to be built a number of other units, then the system should undergo an extensive evaluation and the

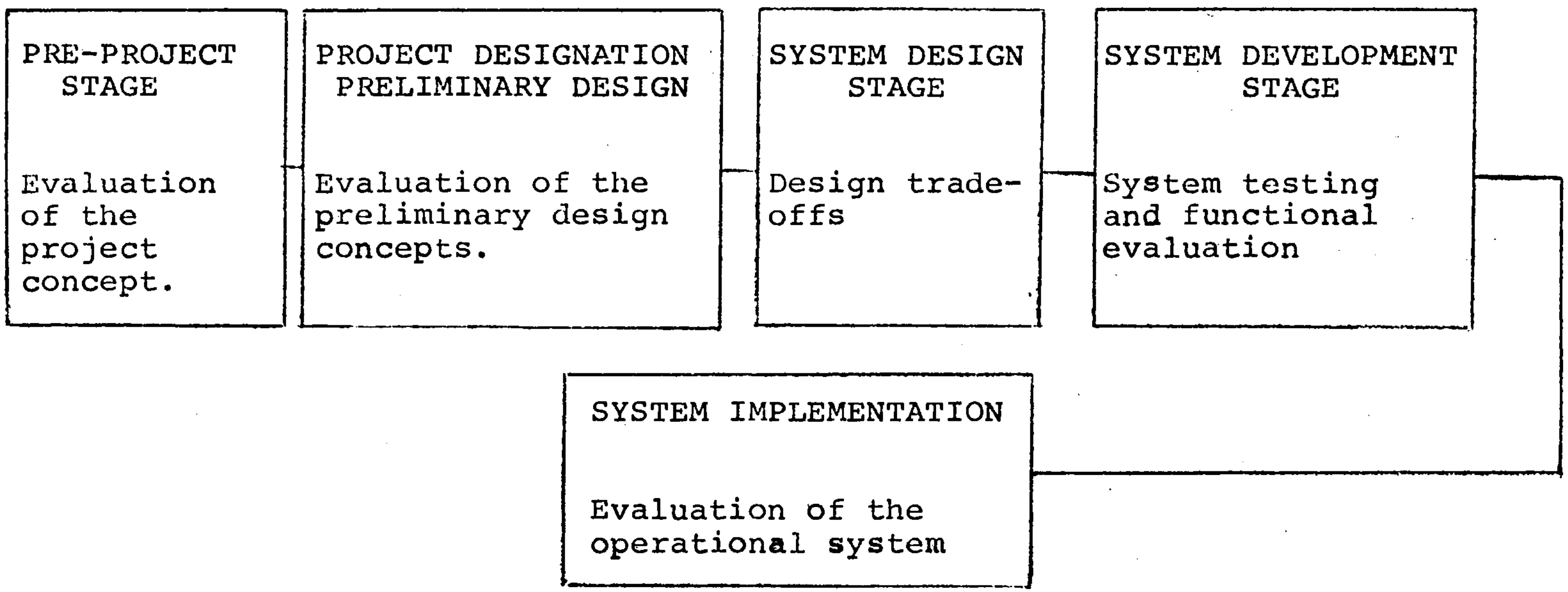


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Figure 2. System Effectiveness Applied to Project Phases

results of the evaluation should be factored into the feed-back loop as illustrated in Figure 3. The corrective actions obtained through the feed back process will involve a greater cost than those actions taken in the early program phases but this cost will be less than that is involved in having an ineffective operating system.

Systems are developed to meet the requirements of certain specific missions. The requirements and the nature of the missions are specified by top management or the individual user. It must be recognized that the system can only be evaluated in relation to the specific mission requirements and the parameters of the subsystem which are utilized to meet these requirements. The relationship between mission requirements and the system used to achieve them is illustrated in Figure 4.

The elements which go to make up any system are modified by the mission which they are to perform. The evaluation of the same physical element in two different systems may therefore be completely different. Additionally the criteria by which the subsystem is to be evaluated may vary greatly with the mission of the system. The criteria by which the system will be evaluated are supplied by the user of the system. However, the user must develop these criteria in conjunction with the designer. It is the designer who will know the parameters which must be considered in relation to such evaluation criteria.

The designer, as well as the analyst, is faced with

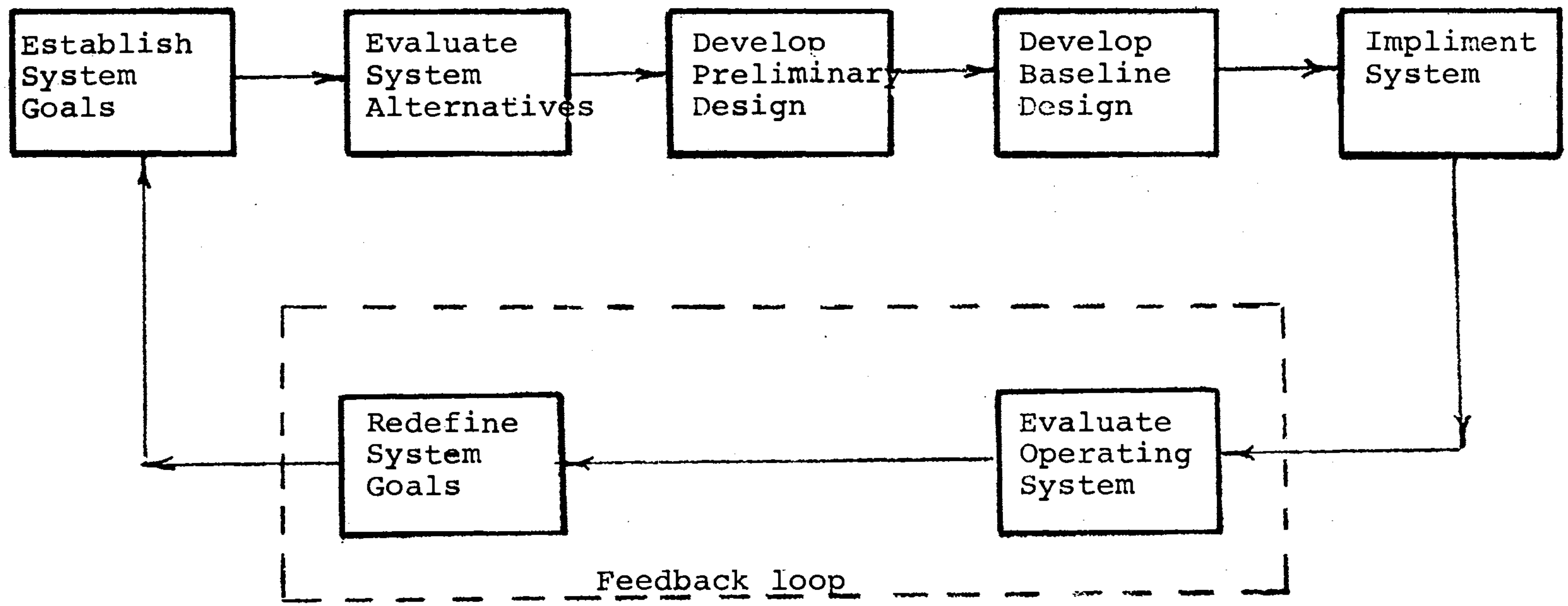


Figure 3. General Flow Diagram for System Effectiveness

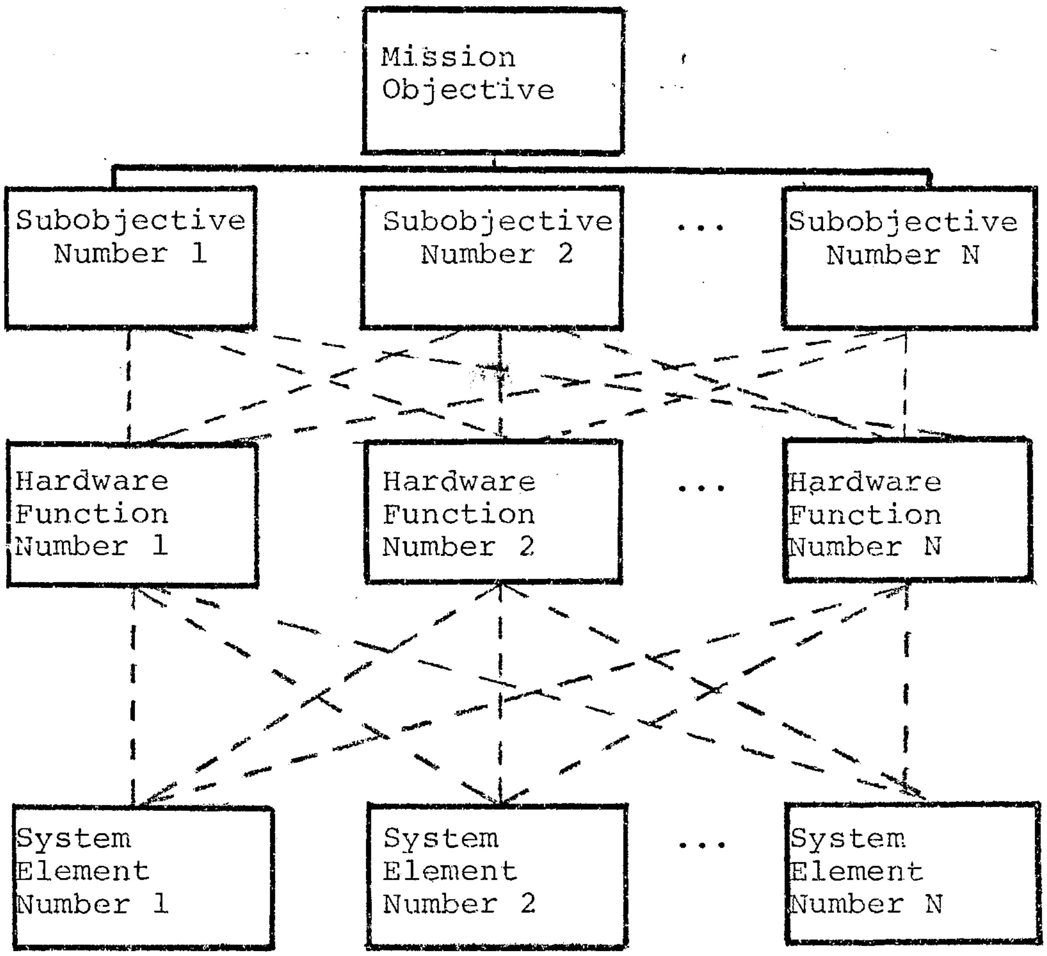


Figure 4. The Relation of Hardware Elements to the Mission Objectives

the problem of the conversion of a specific set of mission goals to a qualitative or quantitative set of system performance indicators. This conversion process requires an analysis of all factors of the hardware and/or human interface. The analyst must evaluate the system effectiveness on the basis of a set of discrete parameter values. These values must be determined in such a manner that the evaluation of all alternate systems concepts will be consistent. It is this evaluation which forms the basis for systems effectiveness analysis.

## The Evaluation of System Effectiveness

The methods utilized to evaluate the effectiveness of proposed or operational systems design are many and varied. They range from the gross qualitative evaluation of the performance of elements in the system to the quantitative evaluation of operational performance data. The technique utilized depends on both technical and management factors. Any design reflects the management philosophy and the evaluation of the design will also be a result of this management philosophy. The technical factors involved include the maturity of the design, the competence of the design personnel, the phase of the program, and the availability of analysis personnel.

Contrary to popular belief the concept of Systems Effectiveness is not new but rather is an outgrowth of several subelements such as cost effectiveness and design evaluation. The term system effectiveness can be traced back prior to 1958 in the literature of reliability and operations research. The concept of systems effectiveness is the extension of the effectiveness concept to cover a number of parameters which may be of importance to the evaluation of the system.

The initial intensive effort directed at the concept of system effectiveness was begun by the military in the mid 1960's. The Air Force Systems Command undertook an extended study of the problem, under the heading of WSEIAC, Weapons Systems Effectiveness Industrial Advisory Committee. As the name implies, this committee was composed of individuals in the aerospace industry who would act in an advisory capacity only. Also, the results of this committee's activity was directed at military weapons systems alone.

The central element of WSEIAC was the G-47 Committee of the Electronic Industries Association. The G-47 Committee, which had done previous work in the area of systems effectiveness, was virtually absorbed by the larger WSEIAC effort (6).

The factors which contributed to the establishment of the WSEIAC are summed up in the introduction to the Chairman's Final Report:

> In recent times, designers have been faced simultaneously with even more novel demands and acutely limited test data. Performance requirements invariably include severe reaction times which can be met only by closely integrating personnel, procedures and hardware. At the

> same time, program cost limitations, accelerated development schedules, and lack of opportunity for complete systems tests prior to operational deployment have reduced the opportunity to obtain extensive operational usage data. Accordingly, what was once merely considered desirable is now considered mandatory -- an integrated methodology of system management using all available data both to pinpoint problem areas and to provide a numerical estimate of system effectiveness during all phases of the system life cycle (6).

The committee was formed into five task groups; each to investigate a separate area of the system effectiveness problem. The results of the work of these task groups is summarized in the Chairman's Final Report.

The committee defined system effectiveness as "a measure of the extent to which a system may be expected to achieve a set of specific mission requirements and is a function of three primary components: availability, dependability, and capability" (7). The components were defined by the committee as follows:

> AVAILABILITY: The probability that the system will be ready for operation when it is called upon to function.
>
> DEPENDABILITY: The probability of the system completing its mission satisfactorily given that it was available at admission initiation.
>
> CAPABILITY: The measure of the ability of the system to achieve the mission objectives given the system conditions during the mission.

The relationship between these three basic components can be seen in Figure 5. Each component is seen to have either a primary or a secondary interrelationship to the others.

The capability component of the WSEIAC definition is

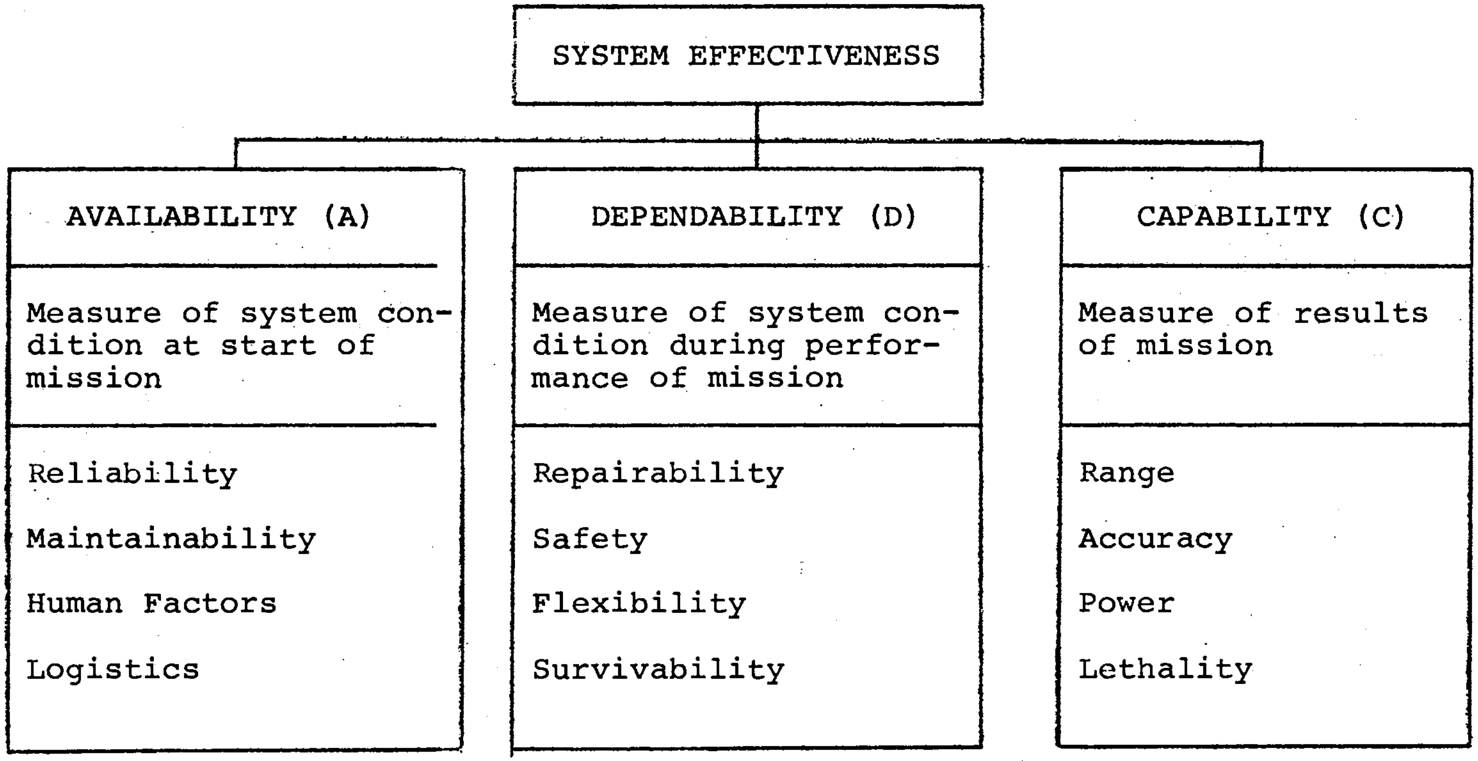


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Figure 5. WSEIAC Concept of System Effectiveness

the most difficult to establish in practice, due to the large number of factors which contribute to the performance characteristics of the system. The question of validity may well be raised if different parameters are utilized in arriving at the capability component. The value of the qualified system effectiveness approach lies not in the number itself but rather in the relative comparison between alternative system configurations or between system evaluations at various points in the system development cycle. As Thomas C. Rowan, Vice President and manager of Advanced Systems Division, System Development Corporation, pointed out in hearings before Congress, systems analysis is:

> Examination of reasonable alternative configurations of system elements that approximate optimal system performance and the determination of the consequences of each configuration in terms of feasibility, acceptability, and cost effectiveness (8).

A review of the major findings of the WSEIAC will provide an insight into the basic philosophy behind military systems effectiveness evaluations. As stated previously, WSEIAC was concerned with the evaluation of weapons systems and their criteria of availability,dependability and capability were established in this relationship. These parameters rely heavily on a firm mission definition which can be related to the discrete hardware elements of the system. Due to the complexity of common weapon systems the committee reached the conclusion that the best approach for evaluation was an analytical study. The systems description to be utilized under this analytical study contained the following elements:

1. Identification of alternative system configuration.

2. Configuration documentation of the selected system, followed by

3. A system summary description.

The committee felt that during the concept phases of the system design cycle steps 1 and 3 form a logical sequence. In the latter part of the system development and acquisition cycles the emphasis will shift to steps 2 and 3 (9). As with most systems effectiveness analysis, the committee's recommendations were based upon an approach to a figure of merit for the system. While some earlier studies had relied upon a qualitative figure of merit, the WSEIAC Committee determined to establish a quantitative figure.

The Committee's models were to be constructed on the basis of individual systems requirements and therefore could not be utilized for multiple systems application. It was pointed out that the model structure must be tailored to fit the data available at the given point in time. It is also necessary to establish at an early point in the development cycle the system constraints within which the system must operate. The committee recommended a four step process for the actual model construction. This process consisted of

1. List assumptions.
2. List variables and define model parameters.

3. Construct effectiveness models.
4. Construct cost models.

The assumptions utilized in model development are of extreme importance for if reality is violated the model will itself become ineffective.

Data acquisition forms the background of the military weapons systems effectiveness evaluation. The data utilized must reflect a consistent and accurate view of the various systems configurations. Once the data has been collected, the model may be implemented in what the committee considered the six essential steps:

1. Calculate figure of merit.
2. Perform tradeoffs with constraints.
3. Insert calculations with standard reference.
4. Calculate effect of risk and uncertainty.
5. Calculate system parameter sensitivity curves.
6. Interpret significant findings.

The output of these studies would be provided to management in the form of summary reports. These reports should contain system quantitative requirements, current system status, trends, summary of problem areas, optimum allocation of resources, and risk and uncertainty qualifications.

WSEIAC Tas Group 5 has identified six segments of management that must play a major role towards the overall evaluation of systems effectiveness. The first three of these segments fall into the category of resource development and include:

1. Data acquisition;
2. Technique development;
3. Personnel development.

The second group concerns resource applications and include:

4. Program planning.
5. Input surveillance.
6. Output evaluation.

It can be seen that the committee's approach to systems effectiveness goes far beyond the simple evaluation of a single parameter. It is rather an integrated approach involving multiple segments of both operational and support elements of the organization.

The Navy has also done extensive research in the area of systems effectiveness evaluation. As with the Air Force group, the Navy's approach was directed primarily at a quantitative evaluation of the various parameters which contributed to the effectiveness of land and shipboard systems. The Navy's criteria for the evaluation of system effectiveness consisted of the following:

1. Performance;
2. Availability;
3. Utilization.

The relationship between these factors can be seen in Figure 6.

The Navy has gone to considerable depths in the implementation of their concept of systems effectiveness.

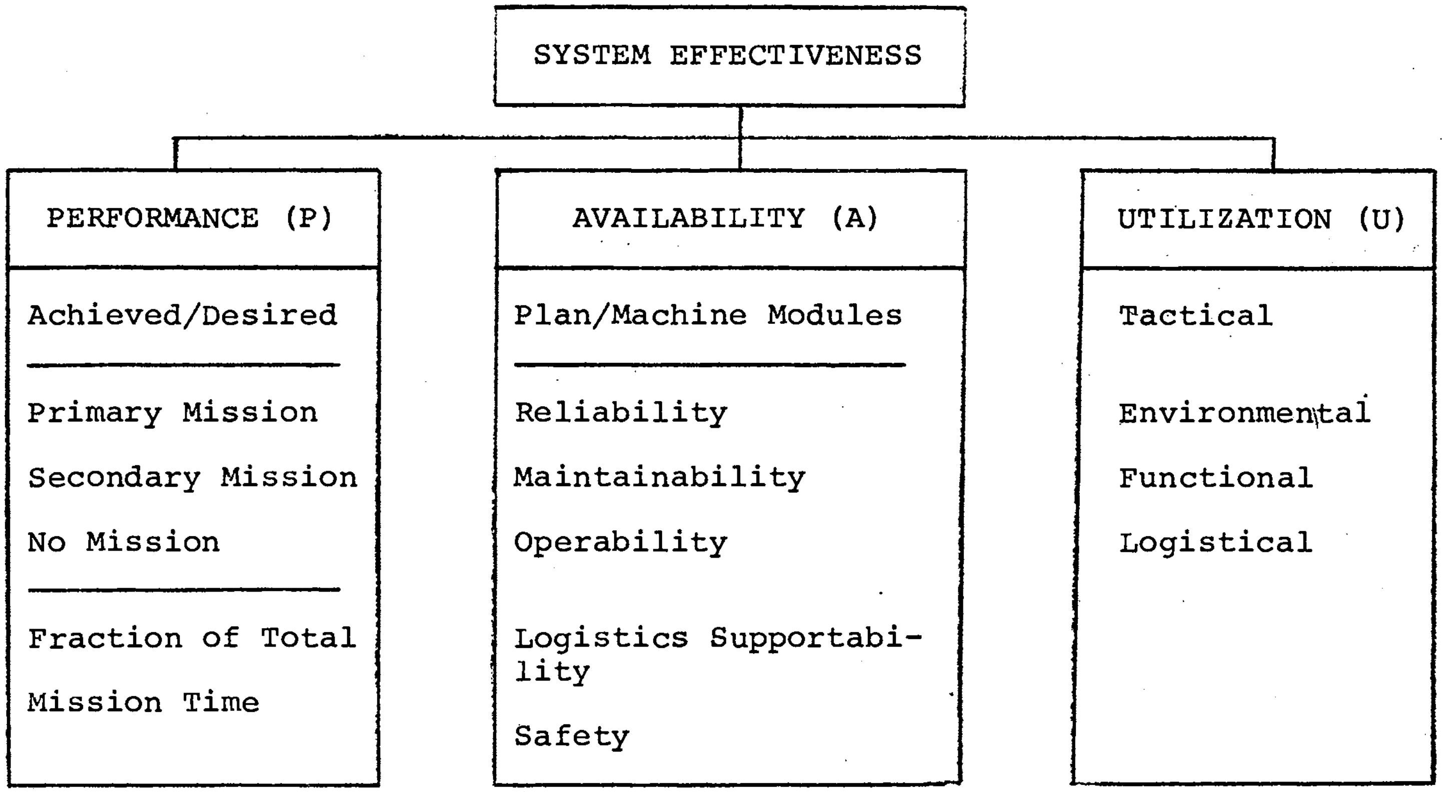


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Figure 6. The Navy Concept of the Components of System Effectiveness

They have placed considerable emphasis on the utilization of existing disciplines within the structure of the new system effectiveness evaluation program.

The system effectiveness training courses offered by the Navy have endeavored to instill in the project management personnel the idea of an approach to systems evaluation which is based upon an interrelationship of systems parameters rather than on a suboptimization of individual parameters. The Navy's approach to systems effectiveness evaluation can be summed up as follows:

> Effectiveness evaluation does not replace systems engineering but rather is one procedure for assessing a systems engineering effort. In fact systems effectiveness evaluation is a major part of systems engineering and not a separate commodity. For example, in every new development a system engineer is required to define a system model of the functions and this definition must be founded on such requirements as primary mission, mutuality mission, complexity, degraded performance, automative performance modes, mission environments, etc., (10).

The Army's approach to system effectiveness consists of the evaluation of an effectiveness measure based upon

1. Operational readiness
2. Mission reliability, and
3. Design adequacy

The relationship between these factors may be seen in Figure 7.

The Army's approach has been primarily limited to the major weapons and missile systems. As with the Navy, the Army has relied heavily upon the existing project management structures to provide the framework within which systems

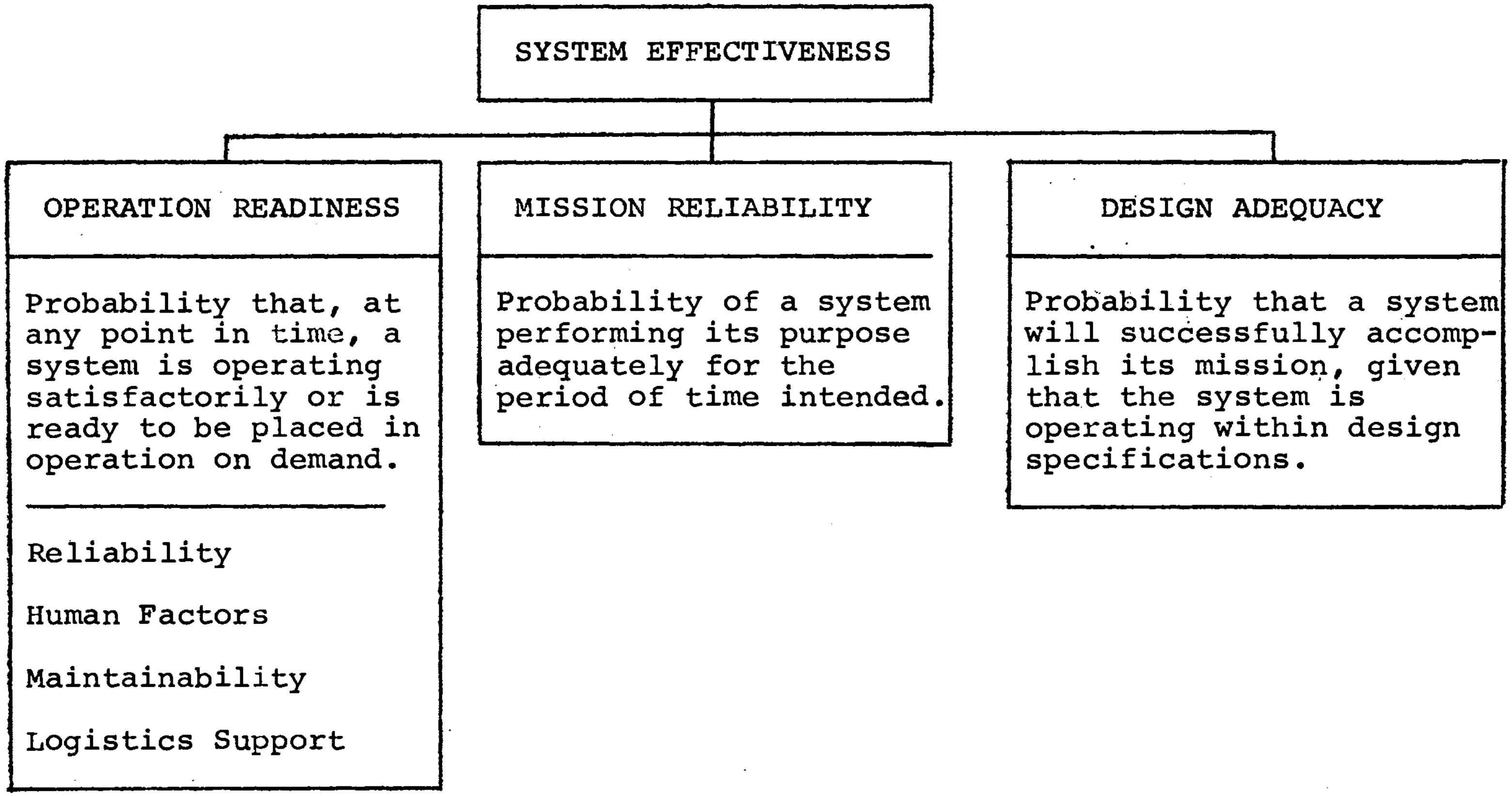


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Figure 7. The Army Concept of the Components of System Effectiveness

effectiveness evaluation may be implemented.

All three services have concentrated on the development of a systems effectiveness measure which can provide an objective view of the worth of a given system configuration (11). This concept can be seen in application to a project in Figure 8.

In recent days one of the most active areas of systems effectiveness evaluation has been the Rome Air Development Center. RADC has taken the output of the WSEIAC Research and has attempted to apply it to the operational Air Force R & D System. They have extended the application of systems effectiveness into this new area and have utilized such techniques as simulation and mathematical programming. They have also examined what has proved to be one of the most difficult aspects of systems effectiveness engineering, that is, the demonstration of the achievement of a given system effectiveness level. It is one thing to be able to quote a number and state that it is the systems effectiveness of a given system configuration. However, it has proved to be quite another matter to demonstrate a comparable level of effectiveness in an operational situation. This strikes at the heart of the utilization question. If systems effectiveness is to be implemented, it must consider a realistic environment.

The RADC structure of system effectiveness can be seen in Figure 9. This structure combines both standard

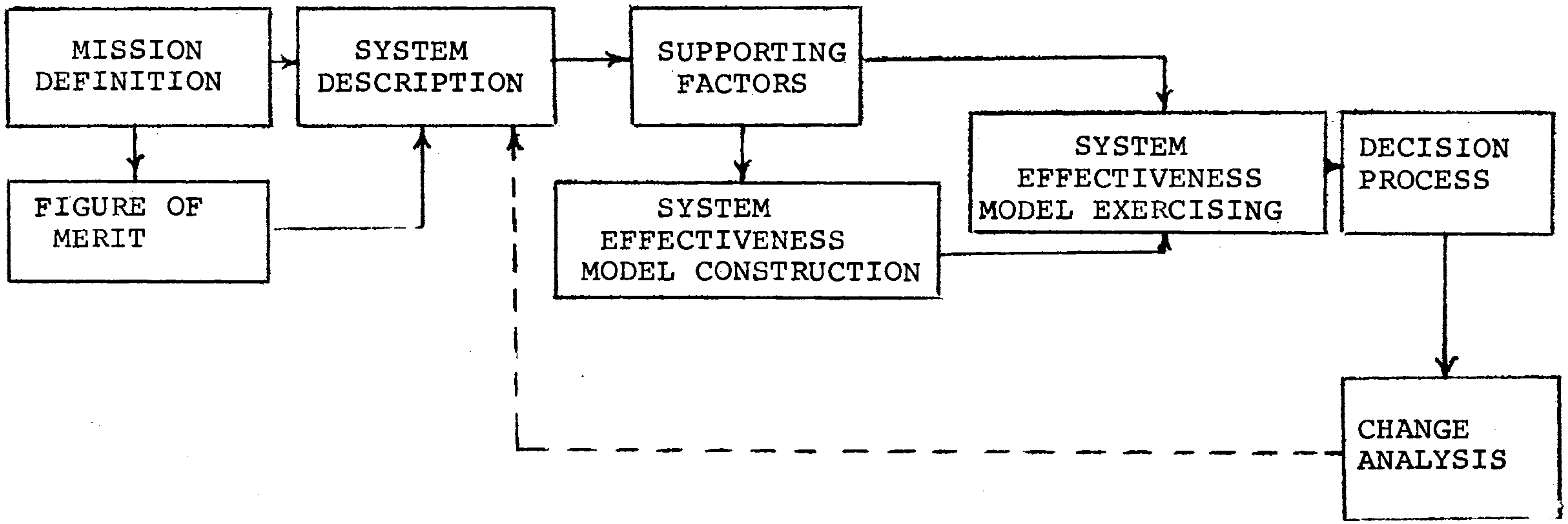


Figure 8. An Integrated Concept of System Effectiveness

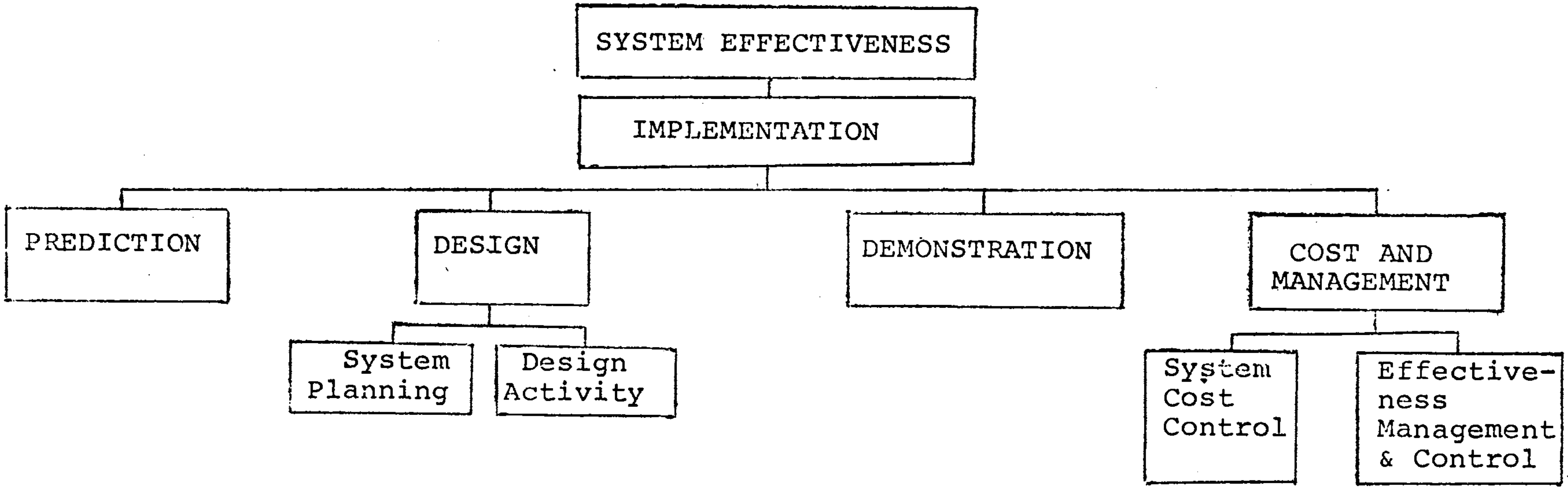


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Figure 9. The RADC Concept of System Effectiveness

and new elements of operational project management situation (12).

All approaches to system effectiveness involve an attempt to analyze the worth of alternative systems configurations; systems configurations which may or may not achieve the desired mission goal. As with all goals, a systems effectiveness goal is established on the basis of the mission requirements and resources available. Figure 10 illustrates the balance which must be maintained between the technical worth of a given system and the resources cost available. This balance is one in which the manager attempts to obtain a workable system having a high probability of achieving mission goals and still live within his resources constraints. As can be seen in Figure 11, alternative configurations differ in both amount of resources required and the effectiveness which they can obtain.

Any action taken during the systems development cycle can potentially have multiple effects upon the various systems elements. Some of these effects will be desirable, however, others will tend to work to the detriment of the system. It is these interrelationships that must be assessed in the evaluation of systems effectiveness.

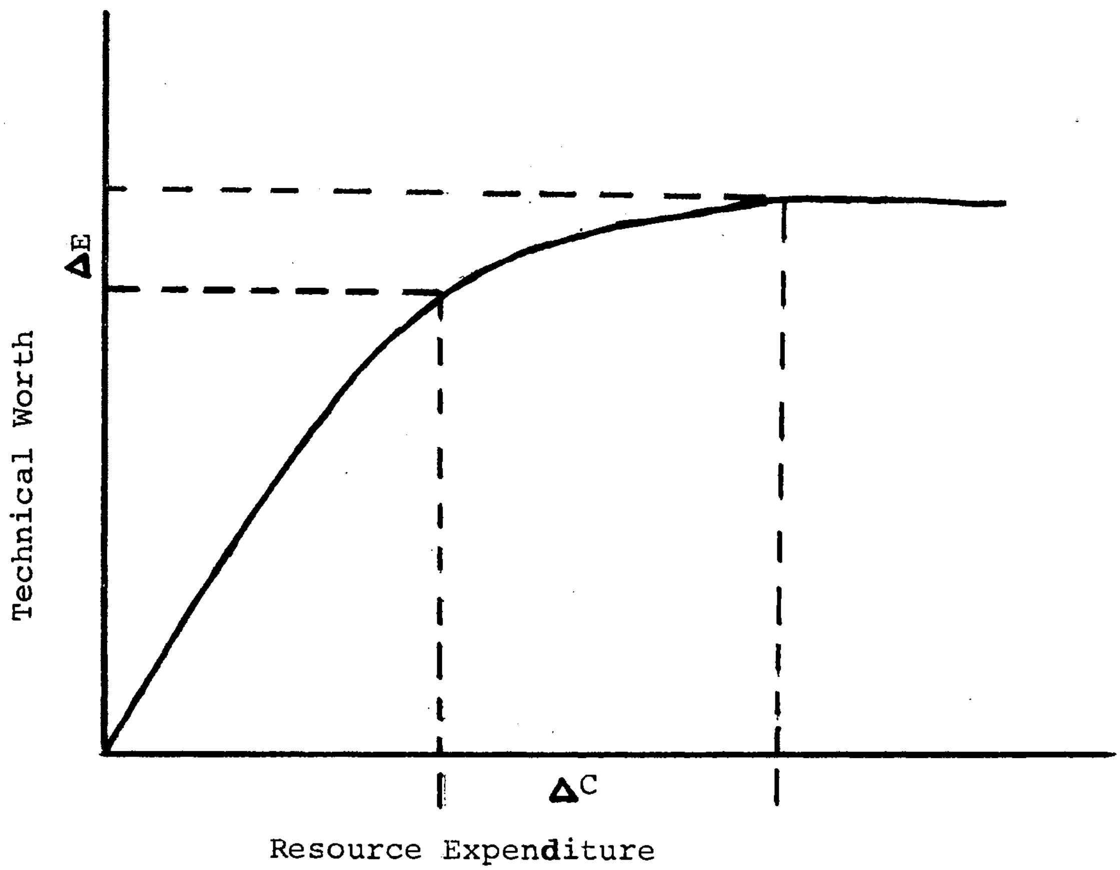



**Figure 10.** Resource Level vs Technical Worth Balance

| Configuration Alternative | Cost | Performance | Schedule |
|---|---|---|---|
| 1 | $C_1$ | $P_1$ | $S_1$ |
| 2 | $C_2$ | $P_2$ | $S_2$ |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| N | $C_N$ | $P_N$ | $S_N$ |

**Source No. 12**

Figure 11. Parameter Contributions of Alternative System Configurations

## Scope and Purpose of Current Study

It has been observed in much of the literature that a general approach to the evaluation of systems effectiveness would be a desirable goal. However, most of the individuals involved in systems effectiveness studies have been concerned with the establishment of criteria relative to a given type of system. In most cases this has been a military weapons systems. The result is a large number of techniques applicable to an extremely limited number of systems.

It has also been observed that while an analytical technique provides an excellent method for examining fixed system parameters, such as weight and cost, it is less than ideal when examining the operational parameters of a system. For complex systems this has often led to a situation in which several models had to be constructed for evaluation of the entire complex. It has been established that simulation is a desirable tool for use in the evaluation of system performance. The value of simulation is derived mainly from the fact that the structure of the system may be modeled and the interrelations within the system may be actively studied. This is seldom the case with a strictly analytical study.

Until recently the state of the art in digital computer languages did not provide for ready access and utilization of multiple languages in a single utility program. However, currently there are available both languages and machines which provide this unique capability. For the first time this allows for the capability of developing a model which incorporates both aspects of an analytical nature and of a simulation nature. This will provide for dynamic examination of various systems alternatives.

It is the purpose of this study to develop a general utility model for the evaluation of systems effectiveness of hardware and hybrid type systems. This model will be developed by utilization of a hybrid approach to computer modeling in that both simulation and analytical computations will be performed within the same program. The model will be designed in such a manner that alternative system configurations can be studied under virtually unlimited environments. User inputs will be simplified to the maximum extent technically feasible.

It is believed that such a model will provide a much needed tool for the evaluation of not only large systems, but small and intermediate size systems also. It is the small and intermediate size systems which have been most neglected in the advance of systems engineering technology for the cost of implementing the techniques of systems engineering is often prohibitive. A general utility program will provide a readily useable method by which a systems analyst may determine which alternative systems configuration provides the greatest possible benefit for his system.

# CHAPTER II

## MODEL DEVELOPMENT

### Background

A model designed to evaluate the effectiveness of a number of system configurations must be flexible enough to provide for system variations and complete enough to provide a reliable effectiveness measure. Because of the shifting nature of system parameters, a model must have the ability to handle both static and dynamic system elements. The static elements will remain constant throughout the given system's mission. The dynamic system elements must have the capability to change as the system environment changes. A consideration of these two basic types of elements will constitute the foundation of the system model.

The mission or missions to be performed by the system must also be factored into the system model. However, if the model is to be general in nature and application, it must have the capability of handling various mission alterations without a significant change to be basic model. The model must also have the capability of reflecting the various degrees of importance expressed by each of the submission objectives. The relative aspects of each mission must also be related to the hardware functions required for their achievement. This relationship will form the basis for the time phase evaluation of the operational performance of the system configurations under analysis.

For the purpose of model development, System Effectiveness will be defined as follows:

> The System Effectiveness of a given system configuration is the relative degree of mission performance of that configuration gaged against a baseline system and the baseline mission or missions to be performed.

This definition involves two basic elements. First, the effectiveness is gaged with respect to the specific mission or set of missions to be performed. Second, the effectiveness of any given system configuration is gaged relative to a standard baseline system.

## Static System Elements

The static nature of certain system elements allows the analyst to perform direct analytical computations on these elements. The static system element must remain constant with respect to time and must also have a predictable interaction with all other system elements.

For the purposes of this model, the static system elements will be referred to as Type 1 elements. The value of each Type 1 element will be supplied in units appropriate to that element, for example, weight would be supplied in pounds. The supplied value of the static element will be referred to in a value relationship consistent with the units in which the element's value is supplied. The static system elements for the given system under analysis would take the following form:

$Vs_{ijk}$ - element value

where

i - Subsystem index

j - Component index

k - Parameter index

Parameter Value Modifications

The value of each static element will be adjusted to a standard base. The adjustment will be made on the basis of a selected distribution ranging between 0 and ∞. The standard distribution chosen for these adjustments is the negative exponential distribution. The conversion relationship is illustrated in Figure 12. The negative exponential distribution was selected due to the natural limits which it imposes. The adjusted parameter value will tend to reflect the contribution of the increasing base parameter values while limiting the adjusted value to a maximun of 1 and a minimun of 0. The system configuration under analysis will be evaluated at the lowest level compatible with the mission level objectives. This type of evaluation will provide a tie between the mission, which is often of an abstract or scientific nature, and the technical hardware functions required to achieve that

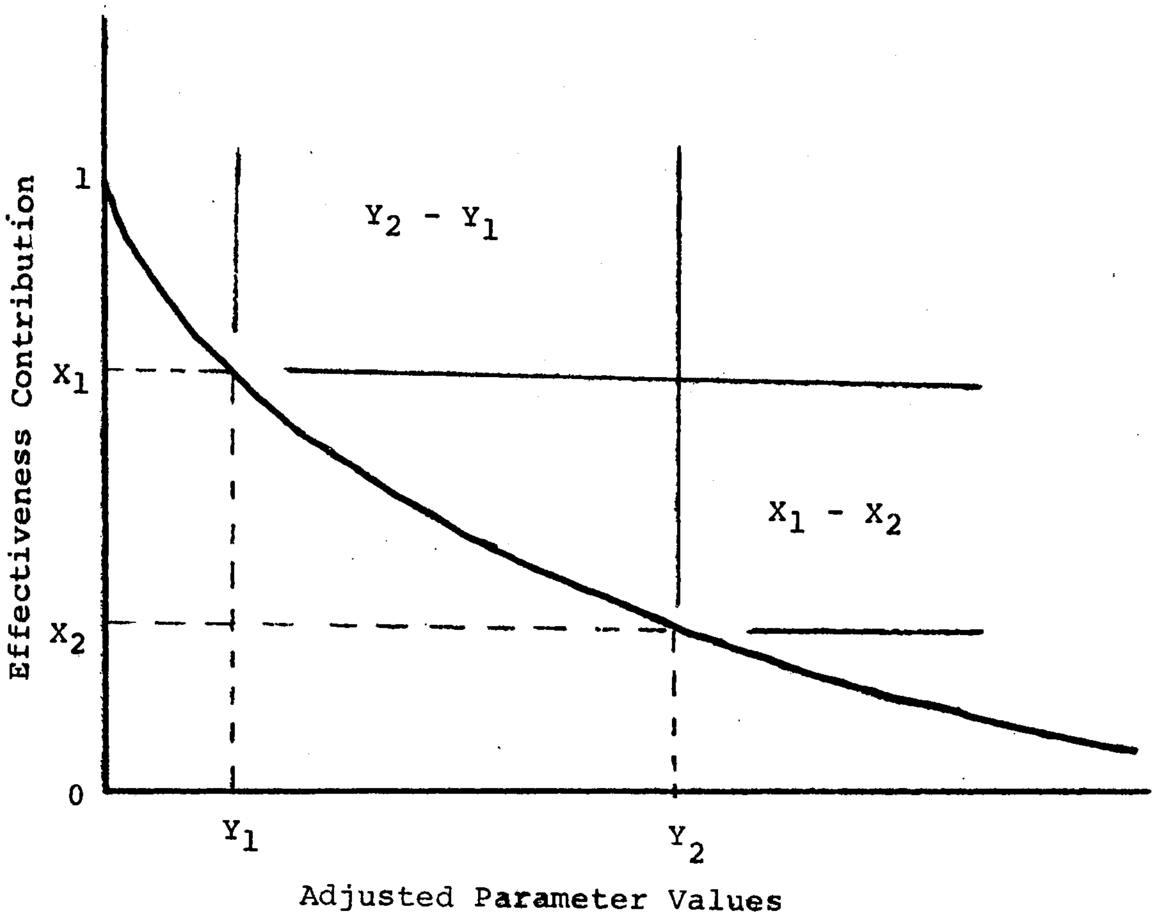



Figure 12. Exponental Adjustment Relation

mission. The input level for the hardware will be determined by the mission conversion sequence. This sequence will allow for a weighted conversion of the various aspects of the submission objectives into a discrete functional hardware relationship. The procedure for accomplishing the conversion of the mission success definition to the relative contribution of the hardware elements will be presented in later sections of this paper.

The adjusted parameter value constitutes the basic comparison element between the alternate system configurations. The adjusted parameter value must however be weighted as to its relative importance to the performance of the system. The value thus obtained must again be adjusted to reflect the importance of the individual subsystem or component to the total system's performance.

## Importance Weighting for Static Parameters

The importance weighting for the various characteristic parameters may be accomplished in a number of different ways. However, the easiest manner is a simple ranking of the various parameters according to their relative importance to the performance of the system. This form of ranking allows the manager to establish relative bench marks and then to systematically build on these bench marks until all parameters have been slotted. This technique may be easily implemented but alone the individual rankings are not mathematically comparable. To allow for matematical compatibility, the simple ranking technique must be allied with a technique which can illustrate the relative importance of each parameter value.

The exponential weighting technique provides for the relative weighting of a set of characteristic parameter values with respect to a predetermined baseline sequence. The desirability of exponential weighting is multifold: first, it provides a method whereby the relative importance of a set of parameters may be illustrated; additionally, the technique allows for an uncomplicated computational generation of weighting factors.

The basis of the technique of exponential weighting is a convergent infinite series in which $\alpha$ represents the amount of importance attributed to the most important parameter. The second most important parameter would be given a weight of $\alpha(1 - \alpha)$ and the third would be given $\alpha(1 - \alpha)^2$. This order would continue until the last parameter had been assigned a weight. The total of all weights would equal to unity as illustrated in the following series:

$$\alpha + \alpha(1 - \alpha) + \alpha(1 - \alpha)^2 + \ldots\ldots + \alpha(1 - \alpha)^N \qquad (1)$$

The sum of the above series is:

$$\alpha/(1 - (1 - \alpha)) \qquad (2)$$

when

$$(1 - \alpha) < 1$$

Equation (2) can be resolved into $\alpha/\alpha$ which is the unity sum of all the parameter weights.

The establishment of the baseline sensitivity factors for a system configuration is dependent primarily on the number of characteristic parameters which the model is to consider and the relationship between these factors. Table I contains a representative listing of the convergence pattern for various $\alpha$ values and various numbers of parameters. The entries in Table I were complied on the basis of the summation of the first two hundred elements of Equation (1). While in theory any value of $\alpha$ may be chosen, it can be seen that practical limitations are imposed by the nature of the convergence pattern. To aid the user, a special weighting routine has been included in the computer programs which implement this model. This program is set in such a manner that the only factors which are required are the number of parameters to be weighted and the ranking of these parameters.

## Mission Importance Contributions

The complex systems encountered today are often designed to accomplish a number of interrelated mission objectives. These submission objectives are commonly of a nontechnical nature such as scientific scanning or resources management. The scientific or social objectives must be related to the specific objectives of the basic functional system. The process by which this relationship is established is based on a ranking of the objective importance of the functional goals of the system in

TABLE I.

SUMMATION OF THE EXPONENTIAL WEIGHTING SERIES
FOR DIFFERENT $\alpha$ VALUES

| | Values | | | |
|---|---|---|---|---|
| N | .05 | .10 | .15 | .20 |
| 1 | .05 | .10 | .15 | .20 |
| 10 | .4012 | .6513 | .8031 | .8925 |
| 20 | .6415 | .8783 | .9612 | .9885 |
| 40 | .8715 | .9851 | .9985 | .9999 |
| 80 | .9834 | .9998 | **** | **** |
| 100 | .9940 | .9999 | **** | **** |
| 150 | .9995 | **** | **** | **** |

**** unity

relation to the submission objectives of the mission to be performed. Figure 13 illustrates the basic conversion method. Each basic mission objective is ranked with respect to the relative importance of that objective to the overall accomplishment of the primary mission objective of the system. The various submission objectives may then be weighted utilizing the exponential weighting method.

The specific functional objectives which the system is designed to accomplish must be structured on the basis of the performance of the separate system elements. Figure 14 represents a method for reflecting the contribution of each system to the accomplishment of the various mission objectives. The matrix structure allows one to rank the contribution of each subsystem to the individual mission objectives. The ranked values are then weighted utilizing the exponential weighting routine. The adjusted weighting factors can then be utilized in the effectiveness formula for the static elements in the system.

## Mathematical Conditioning

The parameter values generated for the specific system configuration must be related to those of all the other candidate configurations. This relationship will be established through the use of a normalization procedure. The basic parameter value is normalized with respect to the same parameter in a baseline system, usually simplex in nature. The effect of this type of normaliza-

Mission Ojectives

| Hardware Functions | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 4 | 3 | 1 | 2 | 5 |
| 2 | 3 | 2 | 1 | 4 | . |
| 3 | 1 | 2 | 4 | . | . |
| 4 | 1 | 4 | . | . | . |

Figure 13. Mission Objective Breakdown

Specific Hardware Functions

| System Elements | 1 | 2 | 3 | | N |
|---|---|---|---|---|---|
| 1 | N | 3 | 1 | | N-1 |
| 2 | 3 | 2 | N | | 1 |
| | | | | | |
| M | 1 | N | 2 | | 3 |

Figure 14. Sub-Function Breakdown Matrix

tion can be seen in Figure 15. The normalized equation takes the following form:

$$E = \mathrm{EXP}\ \{(-\sum_{i=1}^{N} ( Vs_i/V_b )\ W_i )(\sum_{j=1}^{M} C_j/M )\}$$

where $V_b$ is the characteristic parameter value for the baseline system.

## Static Parameter Evaluation

In the preceeding sections, the elements which go to make up the static parameter mathematical model have been presented. The elements of the mathematical model are presented below:

$$Es = \sum_{k=1}^{L} \mathrm{EXP}\ \{(-\sum_{i=1}^{N} ( V_i^* )( W_i ))(\sum_{j=1}^{M} C_j/M )\}$$

where

- $V_i$ - The normalized value of the ith characteristic parameter
- $W_i$ - The importance factor of the ith characteristic parameter
- N - The number of characteristic parameters
- $C_j$ - The contribution of the subsystem to the jth mission objective
- M - The number of mission objectives
- K - The number of subsystems

## Dynamic System Elements

Certain program elements are not stable over time and as such they do not lend themselves to direct analytical study. These dynamic system elements must be examined

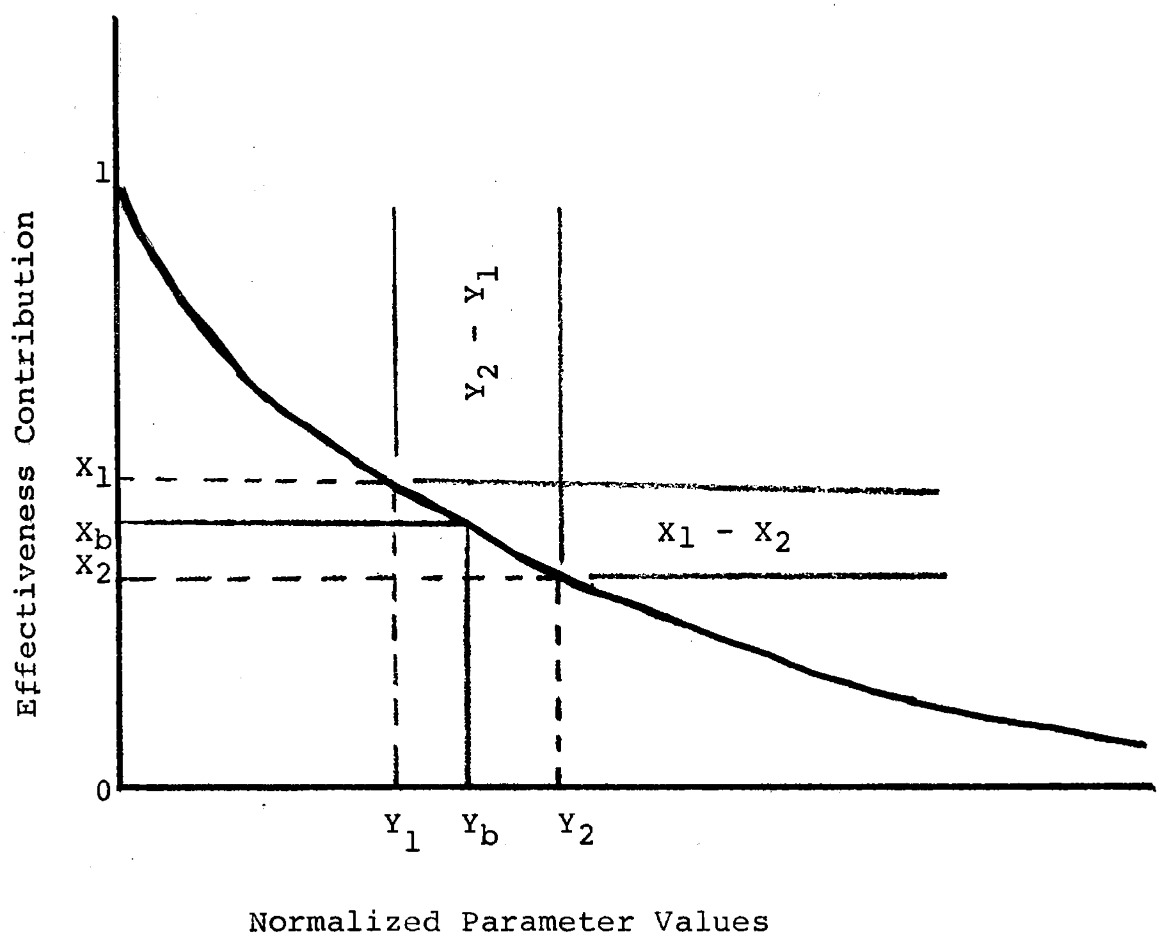



Figure 15. Normalized Exponential Relation

in the environment of the functioning system. This type of examination will be achieved through the use of a simulation model. The simulation model is constructed on the basis of the functional operation of the various system elements. A diagram of the simulation model is presented in Figure 16. As the dynamic system elements may change over time, the simulation model has been so constructed that the various missions may be time phased. The basic element of the simulation model is the component status factor. This factor is an indicator of the operational state of a given component at a given instant in time. The equation for the component status factor would be of the following form:

$$C_s = \sum_{i=1}^{N} W_i \{ (\sum_{j=1}^{M} S_j I_j )/M \}$$

where

$W_i$ - The mission contribution of the various subsystems

$C_s$ - The composite status at any given instant in time

$S_j$ - The individual component status

$I_j$ - The importance of the given component

M - The number of components

N - The number of mission phases

Simulation Process

Unlike the static system elements, the dynamic

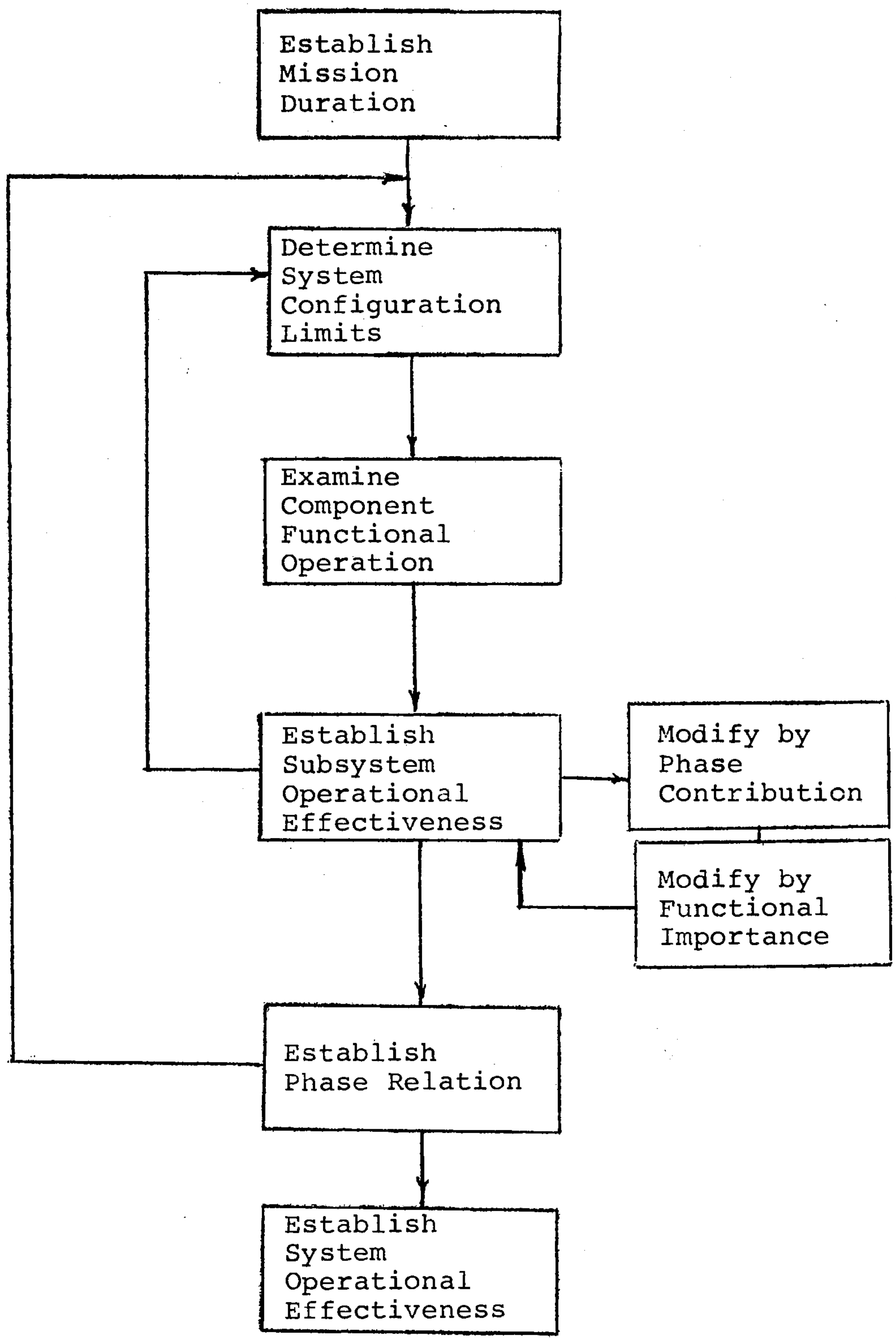



Figure 16. Simulation Model Flow Diagram

elements do not exist in a state in which they can be conveniently studied as separate and distinct units. The simulation model considers these elements as interactive parts of the total functioning system. Reliability is a common dynamic element and serves to illustrate the unstable nature of such elements. During the course of a given mission, reliability is seen to vary considerably. These variations may be due to maintenance activities, operational states of the component, or any number of other causes. The interrelation of the various system factors leads to the analysis of the basic element of reliability in conjunction with all other program elements. The result is a simulation model which is designed to analyze not only the availability of the system at any point in time, but also the capabiltiy of that system for meeting the requirements of the various mission objectives.

## Description of the Simulation Model

Time is a continuous entity, however, for the practical purposes of measurement and analysis we chose to break the continuim into discrete increments. The simulation portion of this system effectiveness model is based on the utilization of discrete mission phases. These mission phases may be as long or short in duration as is required by the mission to be performed. The various system elements are polled as to their condition of operation during each phase of the simulation. The number of operational and nonoperational states available for the system elements is dependent on the system characteristics. The various operational and nonoperational states may be weighted with respect to their importance to the operational capability of the system.

The capability for repair and maintenance is included through the use of an upgrading routine. This routine consist of a polling section and a decision section. The polling section determines if the system element is below its fully operational state; if the item is found to be below this level, a maintenance decision is called for by the decision section. The maintenance decision may vary from no maintenance to full repair of the defective element. The repaired unit is updated to its new operational state and the subsequent time phases consider only this new operational level.

The various operational and nonoperational states encountered by the system elements are recorded and weighted. These factors may then be combined to give a measure of the operational effectiveness of the configuraton under study.

The simulation portion of the hybrid model is written in GPSS-1100. This particular simulation language allows the user considerable flexibility in the construction of the program inputs. All of the inputs for the simulation portion of the effectiveness model are in the form of discrete functions of both name and number type. The program is constructed in such a manner that the user may perform multiple simulations for a given system configuration without recompiling the program. Additionally, the user may alter the configuration being simulated, in order to examine the affects of these alterations. The results of a complete simulation of a given system configuration are reduced to a single value which is used to represent the operational effectiveness of the system configuration under analysis. The interaction of the simulation program with the other elements of the software package will be presented in the next section of this paper. The details of the simulation program are contained in Appendix A.

## Model Consolidation

The two main sections of the effectiveness model, the analytical section and the simulation section, are consolidated through the use of the GPSS interface option. The operational simulation program is executed for each competitive configuration and the results of this simulation are transferred to the computational algorithm. The computational algorithm evaluates all of the static parameters contained in the system. The computational algorithm consist of a number of interrelated FORTRAN subprograms, each controlling a segment of the computational process.

All model outputs are achieved through the FORTRAN section of the composite program. The user is provided with the option of a standard or a special output. Additionally, the user may obtain a standard GPSS output by removing the print hold.

A flow diagram of the hybrid model is presented in Figure 17. The model is designed to be as general as possible, while still preserving the credibility of the output. However, as with all computations of this type, the effectiveness figure has validity only relative to the figures computed for the other alternate system configurations.

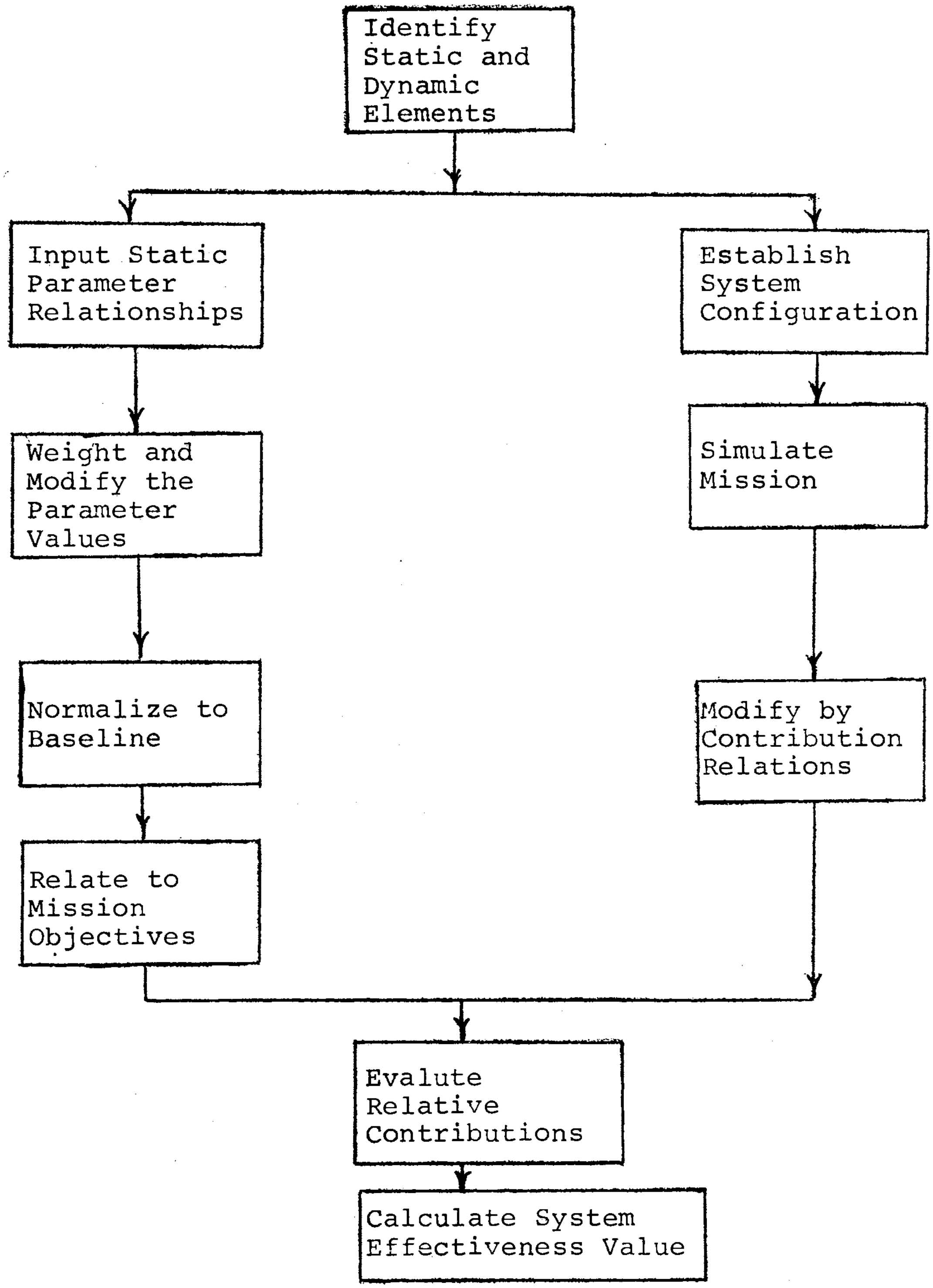



Figure 17. Flow Diagram for the Hybrid Model

## CHAPTER III

## MODEL TESTING AND SENSITIVITY EVALUATION

### Approach

The hybrid system effectiveness model was tested through application to a specific hardware system. The purpose of this trial application was to evaluate the operational performance of the model. The system and the characteristic parameters chosen for analysis were selected because of the previous analysis performed on them by two independent study groups. While no direct comparison can be made between the numerical results of a traditional system evaluation and that of a hybrid type, there can be a comparison made between the decisions which these results imply.

Before appling the model to the test system, the parameter relationships were examined for their responsiveness to change. This sensitivity evaluation was accomplished by the variation of individual parameter values while all other parameters were held constant. The purpose of this evaluation was to assure the model responded in a rational manner to parameter value alterations. As with the application to the trial system, the numerical value of the results of the sensitivity analysis have little importance in themselves. Rather, it is the trend in response to change which is of importance.

## Parameter Variations

For the purposes of sensitivity evaluations for static elements, the parameters of weight and cost were varied and the responsiveness of the model noted. Both of the parameters, weight and cost, are regressive in nature, that is, it would be expected that higher cost or higher weight would tend to reduce the overall system effectiveness.

The analysis on the variation of the cost parameter was made with the model set for a system consisting of eight subsystems. All values and interrelationships except that of the cost parameter were maintained at a constant value. The results of the variation of the cost parameter are illustrated in Table 2. The trend is one of decreasing effectiveness, however, the rate of decrease is not constant. This variation in response is due primarily to the different values associated with the various subsystems and components.

The results of the variation of the weight parameter are illustrated in Table 3. These results indicate a responsiveness to the regressive parameter in that the value of the overall system effectiveness figure is seen to decrease. The rate of decrease is again determined in relation to the importance of the individual components.

TABLE II

SENSITIVITY ANALYSIS FOR THE COST PARAMETER

| Cost Parameter Value | Effectiveness Value |
|---|---|
| 100.00 | .419862 |
| 150.00 | .364210 |
| 200.00 | .317642 |
| 250.00 | .283415 |
| 300.00 | .241587 |

TABLE III

SENSITIVITY ANALYSIS FOR THE WEIGHT PARAMETER

| Weight Parameter Value | Effectiveness Value |
|---|---|
| 500.00 | .512342 |
| 750.00 | .483782 |
| 1000.00 | .449631 |
| 1250.00 | .400013 |
| 1500.00 | .368945 |

The sensitivity analysis of the simulation portion of the hybrid model was accomplished by the variation of the dynamic system elements of redundancy and maintainability. The same basic system was used for the evaluation of dynamic elements as in the evaluation of the static elements. This system was of a multiparameter type consisting of eight subsystems. The results of the variation in the level of redundancy for the basic system is illustrated in Table 4. Increasing the level of redundancy should have an effect of increasing the total effectiveness, and this is confirmed by the analysis.

The results of the variation in the level of maintainability are illustrated in Table 5. Again, the increasing of the level of maintainability has a positive affect on the total value of the system effectiveness figure.

While the variations performed on the static and dynamic parameters do not occur as such in real world situations, the results do tend to indicate the responsiveness of the model to change. The analysis of the interactive aspects of the model will be examined in the application of the model to the trial system.

## Specific System

The system chosen for analysis is the avenonics system of the Space Tug. The Space Tug is an orbit to orbit vehicle designed for the launching and servicing of satellites. The vehicle is scheduled to fly in the

TABLE IV

SENSITIVITY ANALYSIS FOR THE REDUNDANCY PARAMETER

| Level of Redundancy (No. of units) | Effectiveness Value |
|---|---|
| 0 | .181963 |
| 5 | .291934 |
| 10 | .357386 |
| 15 | .392758 |
| 20 | .467290 |
| 30 | .621892 |

TABLE V

SENSITIVITY ANALYSIS FOR THE MAINTAINABILITY PARAMETER

| Level of Maintainability (Percentage maintained) | Effectiveness Value |
|---|---|
| 5% | .204567 |
| 10% | .261492 |
| 20% | .332679 |
| 40% | .452849 |
| 60% | .570034 |
| 80% | .673927 |
| 100% | .768934 |

period from 1979-1990. A detailed description and illustration of the Space Tug and its mission are contained in Appendix B.

The avenonics system is illustrated in Figure 18. This system is primarily an open loop control system interfacing with both the space shuttle orbiter and the ground control. The main feature of this system is the use of a control computer tied to various subsystems through a series of Data Acquisition Units, DAU.

The parameters utilized in the analysis of the avenonics system were of both a static and dynamic nature. On the static side weight and cost were chosen as the characteristic parameters. The subsystem level summaries for the weight and cost are illustrated in Table 6. A detailed cost and weight breakdown is presented in Appendix B.

The dynamic parameters chosen as characteristic for the system include reliability, maintainability, and performance. These parameters are discussed in detail in Appendix B.

The analysis consisted of examining a number of alternative system configurations by use of the hybrid effectiveness model. The alternative configurations which were analyzed are described in Table 7.

## Evaluation of Results

The results of the evaluation of the various system configurations are presented in Table 8. The

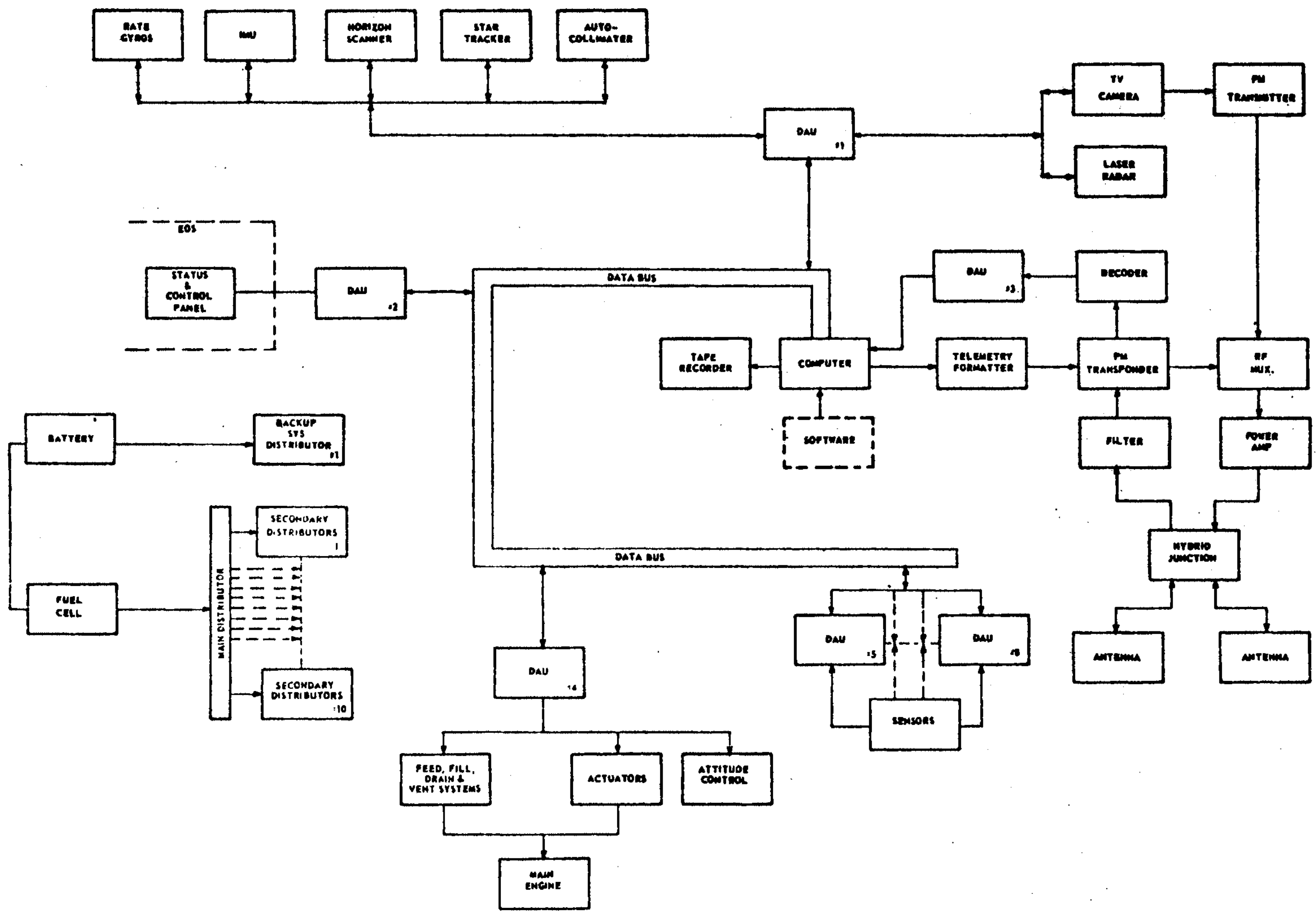



Figure 18. Space Tug Point Design

TABLE VI

STATIC PARAMETER VALUE SUMMARIES FOR THE TRIAL SYSTEM

| Subsystem Number | Cost (Thousands) | Weight (Thousands) |
|---|---|---|
| 1 | 2665.4900 | .2220 |
| 2 | 1936.0600 | .1470 |
| 3 | 1314.6900 | .0780 |
| 4 | 640.4200 | .0470 |
| 5 | 1791.0000 | .3100 |
| 6 | 4931.6000 | 1.2850 |
| 7 | 709.0000 | 1.8500 |
| 8 | 471.0000 | .4160 |
| Total | 14459.2600 | 6.1056 |

TABLE VII

ALTERNATE SYSTEM CONFIGURATIONS CONSIDERED IN TRIAL ANALYSIS

| Configuration Number | Description |
|---|---|
| 1 | A simplex system incorporating no redundancy or maintainability |
| 2 | Redundancy applied to most unreliable areas |
| 3 | Redundancy applied to the most critical areas |
| 4 | Redundancy applied to all units |
| 5 | Functional redundancy incorporated in all computer system elements |

TABLE VIII

THE RESULTS OF THE TRIAL APPLICATION OF THE HYBRID MODEL

| Configuration Number | Effectiveness Value |
|---|---|
| 1 | .186253 |
| 2 | .352574 |
| 3 | .384531 |
| 4 | .243178 |
| 5 | .351890 |

effectiveness value of each configuration has been determined with respect to the baseline configuration, a simplex system configuration. The configurations considered in this study do not represent a complete set of possible configurations, however, they do represent those configurations which the designers and management considered to hold the most promise.

Table 9 presents a comparison between the results of the hybrid system effectiveness model and the results of previous analytical study performed on Space Tug. The various configurations under consideration were ranked in order of their desirability from the total effectiveness standpoint. The actual values produced by the three studies cannot be directly compared due to the different techniques utilized. The previous analysis of the Space Tug had been performed utilizing analytical techniques which considered the system as being static in nature. These studies were of necessity directed at the system state at the beginning of the mission. Additionally, these traditional analyses are limited in the number of mission phases and states that they can consider.

While the system considered under this specific case is of considerable size and complexity, the number of parameters considered are limited. This limitation is based on the ground rules established by the early studies of the system. The real benefit of the hybrid model will be seen in its application to complex parameter interrelationships.

TABLE IX

COMPARISON OF TRIAL APPLICATION RESULTS TO THE RESULTS OF PREVIOUS ANALYSES

| Configuration Number | Ranking | | |
|---|---|---|---|
| | Hybrid | Analysis 1 | Analysis 2 |
| 1 | 5 | 5 | 5 |
| 2 | 2 | 3 | 2 |
| 3 | 1 | 1 | 1 |
| 4 | 4 | 4 | 4 |
| 5 | 3 | 2 | 3 |

# CHAPTER IV

# APPLICATIONS

## Physical System Applications

The model and computer programs developed as a part of this study are currently being utilized to examine trade off options for various space systems. The current applications fall into two basic groups. The first group is composed of complete hardware projects. The second group is composed of individual systems, subsystems, and components. Both groups are basicly hardware orientated with limited external interfaces. The number and complexity of the missions to be performed by the various hardware items also vary considerably.

A potential application for the hybrid model lies in the operational analysis of software systems. The basic software system consist of a number of interrelated routines designed to perform a certain function or set of functions. Certain attributes are desirable in these system and certain attributes are undesirable. The operational performance of a software system is dynamic in nature. The response time at any given point is dependent on the operational state of those program elements contributing to the response. In addition to the dynamic operational parameters the software system is also impacted by a number of static elements. The minimum core requirements for the various elements of the system and the compiler limits of the languages in use are two of these static elements.

With the proper selection and weighting of characteristics parameter values, the hybrid system effectiveness model could readily be utilized to examine the performance of various software configurations. An additional benefit of this application would be the necessary identification of weak areas in the software systems. This type of preliminary software verification would result in shorter debuging periods and more reliable software routines.

A logical extension of the above application would be the evaluation of the effectiveness of hybrid, hardware and software systems. Due to the general nature of the hybrid system effectiveness model, this expanded task may be readily undertaken. While the hybrid system has both hardware and software aspects which are easily identified, the interaction between these aspects is often difficult to accurately define. It is this interactive aspect which provides the environment for an effective simulation study. Relationships which would be difficult to define analytically may be examined through the use of the simulation section of the hybrid model. Due to the interlocking nature of the analytical and simulation portions of the hybrid model, parameter values may be altered from one state to another during the course of a given computer run. This option allows the analyst to redefine program elements during the course of the analysis and to observe the results through the use of intermediate printouts. The evaluation of large scale hybrid systems may well constitute the area of greatest application for the type of model developed in this study.

## Management and Information Systems

The basic concept of evaluating the operational effectiveness of a system on a multidimensional level holds for the management and information systems as well as for the physical hardware systems. In these organizational systems the components are individuals and the subsystems are organizational elements. The mission of these systems are defined in different terms but they are still of a definable nature.

The flow elements in the information system are bits of data. These elements must be processed by the various individuals and groups within the system. The functions to be performed by each processing element are relatively stable, however, the functioning of the entire information complex is dynamic in nature. The flow of data between the various processing elements and the operational state of the processing elements at each instant of time combine to create a constantly changing system. This combination of static and dynamic program aspects requires the analyst to examine the information system on a multidimensional level. Limited size information systems of a hypothetical nature have been tested against the present hybrid model and its associated computer programs. The results indicate that with only minor modification the present model can be used for the evaluation of these organizational systems. The modifications required can be accomplished through the use of the variable imput and processing features of the hybrid model.

Through the use of the standard GPSS printout option, a complete simulation study of the candidate information system may be obtained in conjunction with the normal system evaluation data. This additional information may be utilized to identify possible problem areas in the design. The alternate system configuration may then be reevaluated and compared against the original results.

# CHAPTER V

## SUMMARY, CONCLUSIONS & RECOMMENDATIONS

### Summary

The model presented in this paper is one which is directed toward a quantitative evaluation of a complex situation. The general hybrid system effectiveness model provides for the recognition, evaluation and consolidation of characteristic parameter values in a given system. This model characteristic provides the flexibility required in the evaluation of large numbers of complex and dissimilar systems. The model presupposes that the analyst has given enough time to the preevaluation of the system under consideration. This preevaluation includes:

(1) Identification of the purpose or mission to be performed by the system.

(2) Establishment of the relationship between the various mission objectives.

(3) Establishment of the relationship between the implementing items of hardware or software and the various mission objectives.

(4) The establishment of the characteristic parameters for the various hardware or software elements.

(5) Identification of the contributions made at different intervals of time by each of the system elements.

(6) Analysis of the operational characteristics of similar type equipment.

This analysis provides a baseline for the development of the necessary inputs for the hybrid model. A definite advantage is achieved by the analyst being forced to perform this preliminary evaluation. This type of analysis engenders a more objective evaluation of the various elements of the system.

The hybrid procedure proposed in this paper draws heavily on the subjective evaluation by the manager or analyst of the interrelations presented in the system. The The questionaire utilized to obtain these evaluations is contained in Appendix C. The use of a multidimensional analytical and simulation model provides the analyst with considerable flexibility in establishing the type of analysis which he wishes to perform. The simulation portion of the hybrid model allows the analyst to determine the operational performance characteristics of a given system configuration prior to the actual construction of the system. Due to the general nature of the model, the only fixed values supplied in the standard program are those of the base exponential distribution used for weighting and for adjustment of parameter values. Due to the fact that all parameters in the system are adjusted in a like manner, all adjusted parameter values assume a regressive relationship; that is a higher parameter value, the lower the contribution to the overall effectiveness of the system.

## Conclusions

The hybrid system effectiveness model provides a tool which may be utilized in the evaluation of virtually any system. The limits on the application of the model are derived primarily from the following areas:

(1) The system definition at the point in time that the analysis is performed.

(2) The amount of historical information available on the various elements of the system.

(3) The uniqueness and complexity of the system.

(4) The identification of the true characteristic parameters for the various system elements.

While the amount of work involved in preparing data for input to the computer programs associated with the hybrid model is considerable, such effort should normally be undertaken in any project development program.

The benefits of the hybrid system effectiveness model can best be seen in its application to large and relatively complex systems. While the smaller system may be evaluated by use of the hybrid model, these systems can often also be evaluated through the use of traditional means or through the use of a single state model. The multi state model depicted in the hybrid system effectiveness technique provides the visibility required in the more complex system evaluation.

## Recommendations

Several additional areas of study may prove beneficial in the further application of models of the hybrid type. These will be discussed in the following paragraphs.

One major areas of concern is in the amount of computer time and core storage required to operate in the hybrid situation. Shifting from one compiler to another requires the use of complex programming relationships and consequently the use of an increased amount of computer core storage. Compatible areas of different languages must be identified such that transfers can be made at the appropriate points in the program. While the hybrid model presented in this paper was developed for the use of GPSS 1100 and FORTRAN V, there may exist additional languages which would provide for increased flexibility in this type of programming. Evaluation of these additional options may lead to the establishment of a more economical form of hybrid programming.

Further study may also be directed at the establishment of data bases which would support this type of programming. Many situations exist in which both dynamic and static characteristics are present. The use of a model similar to the hybrid system effectiveness model may allow for more effective evaluation of these situations. One example of such a situation is the urban transit system in which both hardware and human elements are involved. The use of hybrid programming to examine this situation would allow for the flexibility of the simulation model along with the exactness and ease of a computational algorithm.

In addition to the above areas, further research will be required in the application of quantitative models such as the hybrid system effectiveness model to systems on which limited data exists. This research should be centered in the area of the establishment of the true nature and interrelationships of the characteristic parameters for given systems applications. This research would involve the development of more objective methods for determining the importance of the various systems and their internal elements. A better way to aid the manager in the area of element rankings is greatly needed. As systems analysis and management techniques spread to other areas of industry and society, there will be an increasing need for techniques which allow the manager to effectively evaluate and control his situations prior to the occurance of actual problems.

## SELECTED BIBLIOGRAPHY


(1) Barnard, Chester I. The Functions of the Executive. Cambridge, Massachusetts: Harvard University Press, 1968

(2) Heineman, Edward H. "Must All Fighters Cost So Much?" Government Executive (March, 1970).

(3) "Washington Roundup." Research/Development (February, 1972).

(4) "The Shock Waves of Lockheed's Gamble." Business Week (January 9,1971).

(5) "System Effectiveness Engineering Course." Report No. 357-01-3-594, Bureau of Naval Weapons (May, 1966).

(6) "WSEIAC Chairman's Final Report." Report No. AFSC-TR-65-6 (January 1965).

(7) Klion, Jerome "The WSEIAC Concept - Its Applicability/ Validity." Transactions of the 1968 IEEE Symposium on Reliability.

(8) Hoos, Ida R. "A critical Review of Systems Analysis." Report No. NASA CR-61350, Marshall Space Flight Center (December 1968).

(9) Voegtlen, H. D. "A Review of the Major Findings of the Weapon System Effectiveness Industry Advisory Committee." Transactions of the 1966 IEEE Symposium on Reliability.

(10) Sgouros, Pantelis, John Sanderson "Systems Effectiveness and the Navy." Transactions of the 1968 Product Assurance Conference.

(11) Blanchard, Ben S. "System Effectiveness, System Worth, Integrated Logistic Support, and Maintainability." IEEE Transactions (March 1967).

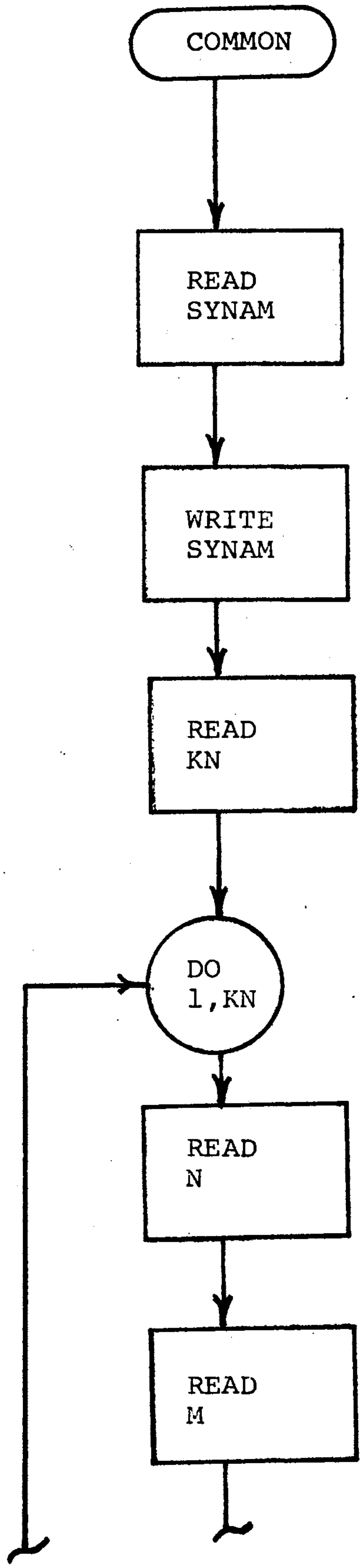
(12) Barber, David [illegible]. "System Effectiveness - How? Where? When?" Transactions of the 1967 IEEE Symposium on Reliability.

# APPENDIX A

# FLOW CHARTS FOR THE MAIN COMPUTER PROGRAMS

FLOW CHART FOR THE FORTRAN SECTION

OF THE COMPUTER ROUTINE




Dimension all array values for the static portion of the program

Input the components which constitute the system configuration

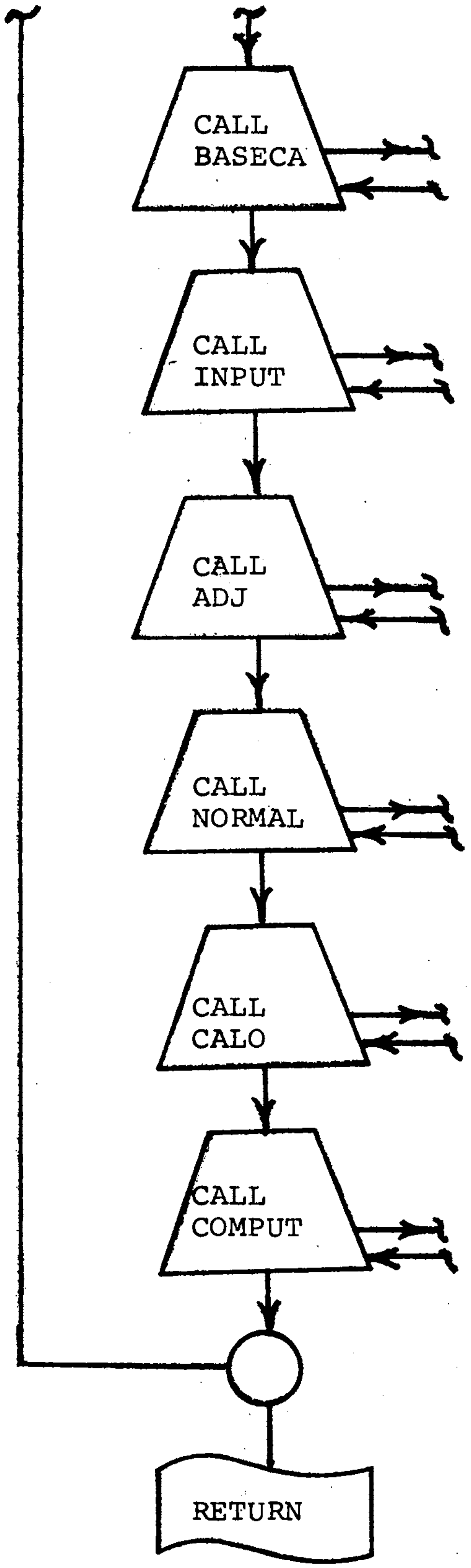
Output dynamic component list

Input the number of configurations to be evaluated

Loop KN times

Input the number of subsystems in the given configuration

Input the number of submission objectives to be performed




Call the subroutine BASECA

Call the subroutine INPUT

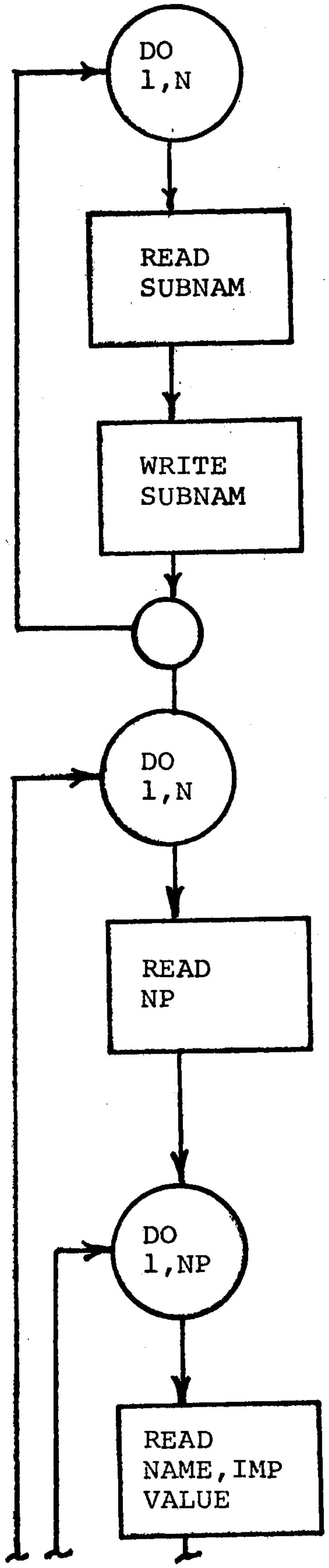
Call the subroutine ADJ

Call the subroutine NORMAL

Call the subroutine CALO

Call the subroutine COMPUT

Return to the simulation portion of the program




Loop N times

Input the names of the subsystems to be evaluated.

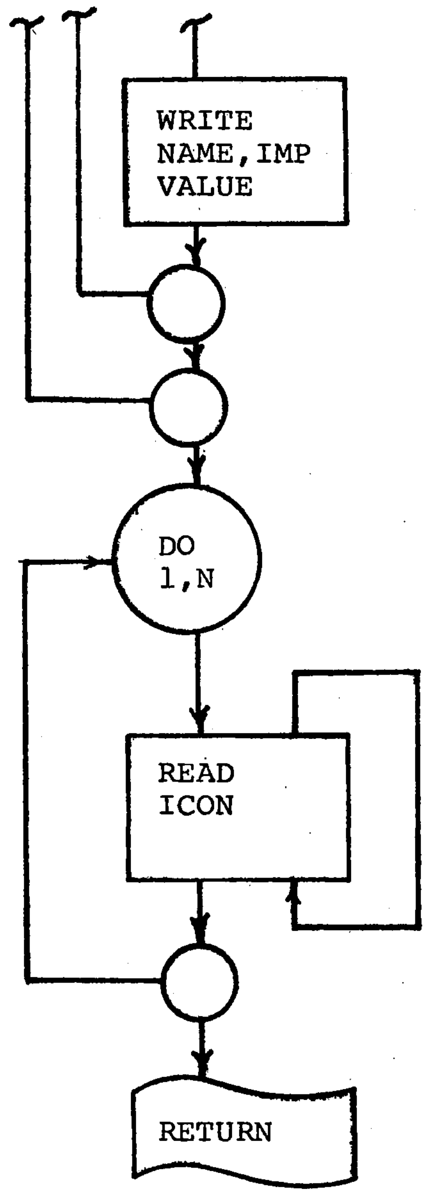
Output the list of subsystem names

Loop N times

Input the number of static parameters to be considered for each subsystem

Loop NP times

Input the name, value, and importance of each parameter

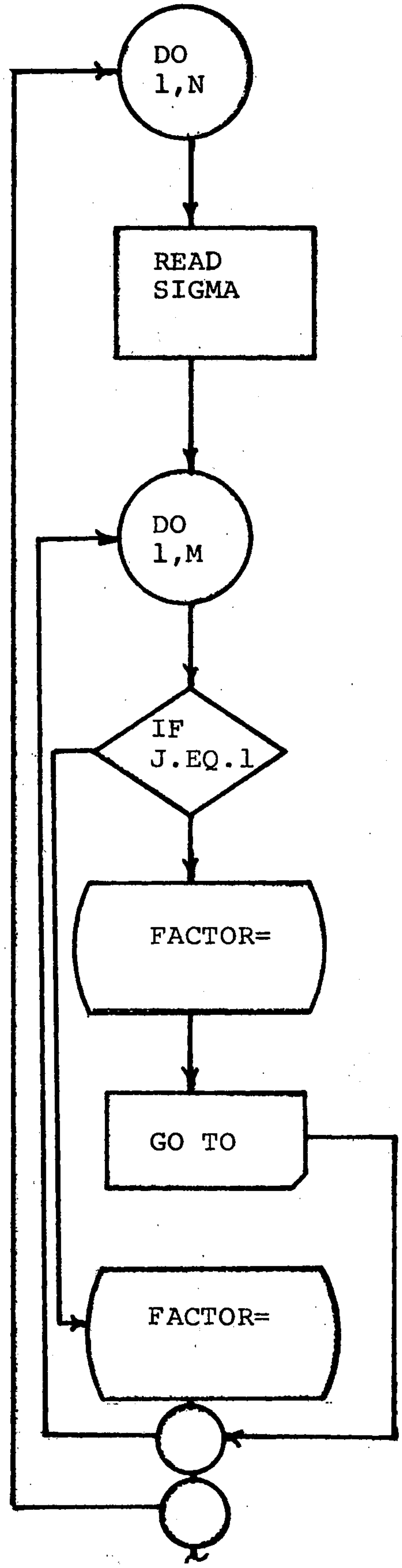



Output the parameter name, value, and importance

Loop N times

Input the mission contribution of each subsystem

Return to the main program




Loop N times

Input the importance weighting factor for the most important parameter

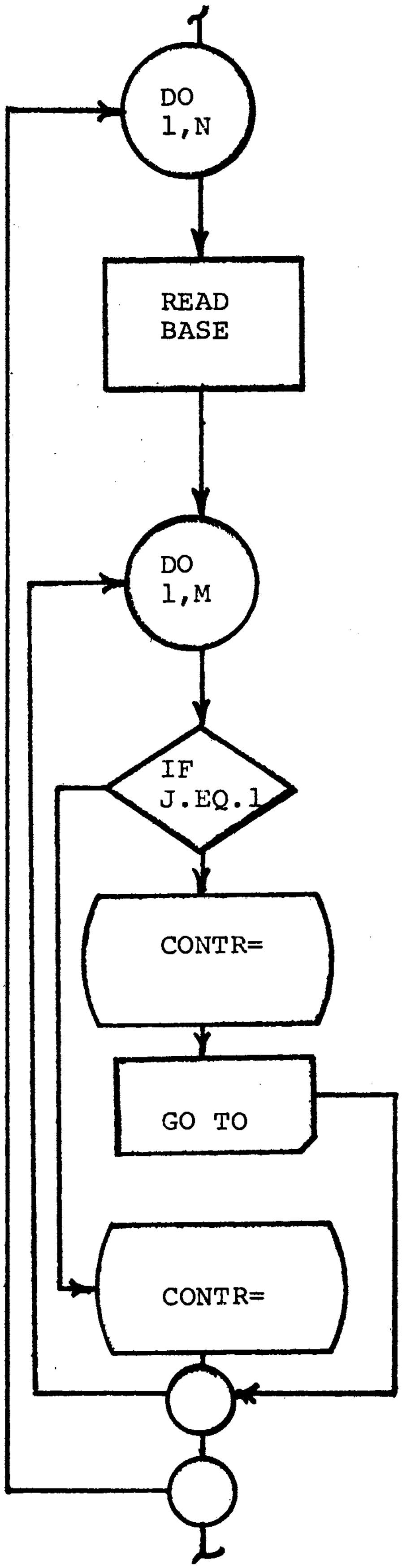
Loop M times

Determine the rank of the subject parameter

Determine the weighting factor for the parameter

Transfer

Determine the weighting factor of the first parameter




Loop N times

Input the importance weighting factor for the most important objective

Loop M times

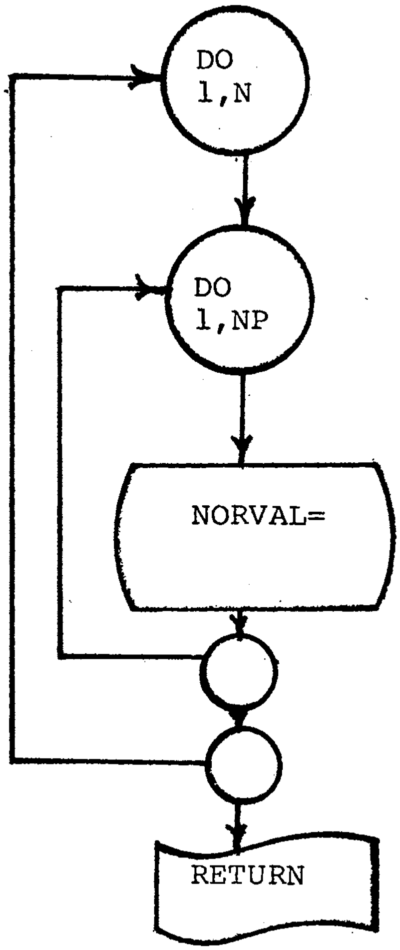
Determine the state of the mission objective

Determine the subsystem contribution to the given objective

Transfer

Determine the subsystem contribution to the given objective


Return to the main program

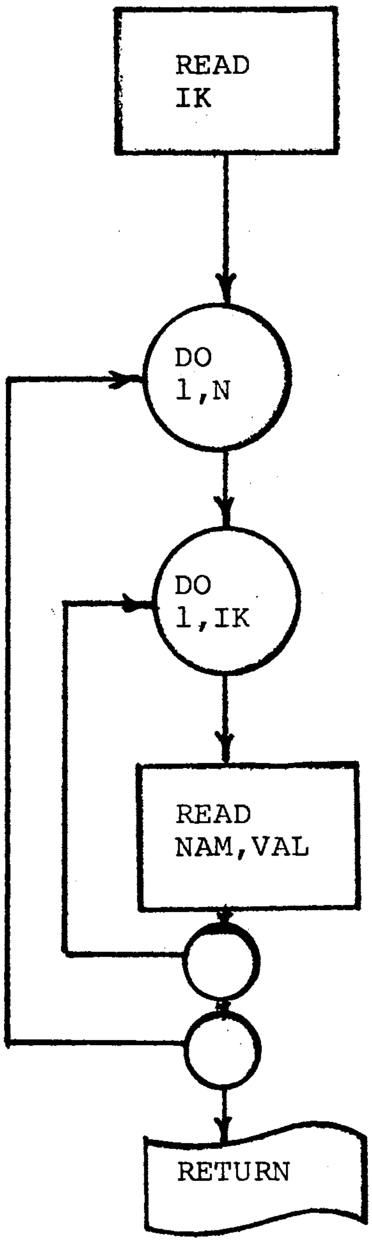



Loop N times

Loop NP times

Determine the normalized value for all parameters in the configuration

Return to the main program



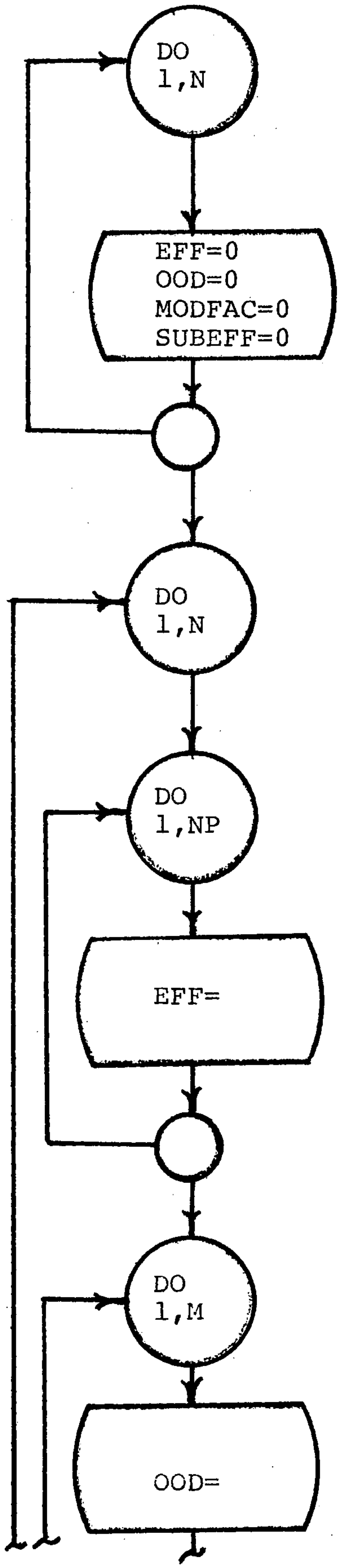

Input the number of parameters to be considered in the base system configuration

Loop N times

Loop IK times

Input the name and value of the parameters in the baseline system

Return to the main program




Loop N times

Set all system accumulators to zero

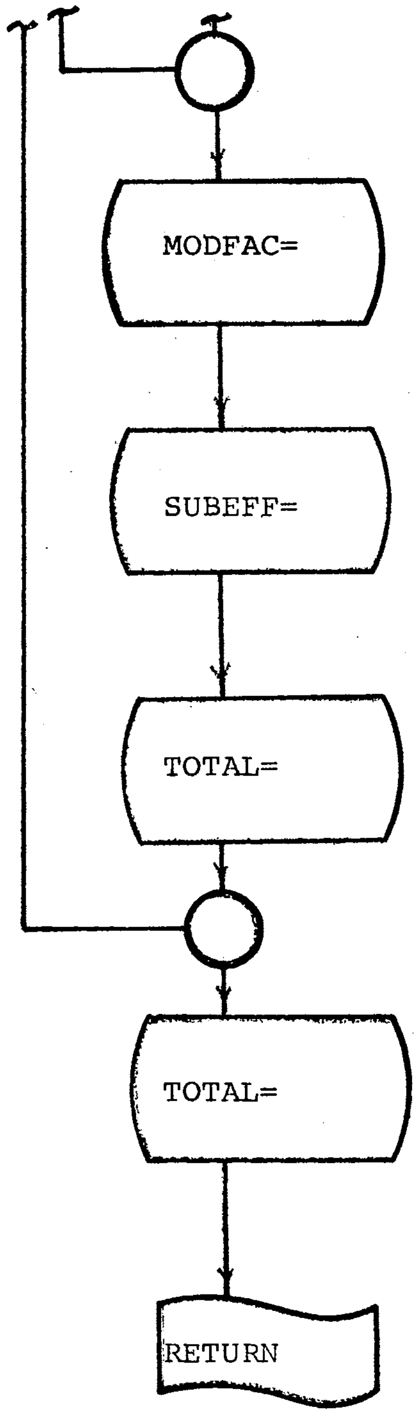
Loop N times

Loop NP times

Determine the parameter totals for each subsystem

Loop M times

Determine the mission objective contributions of each subsystem



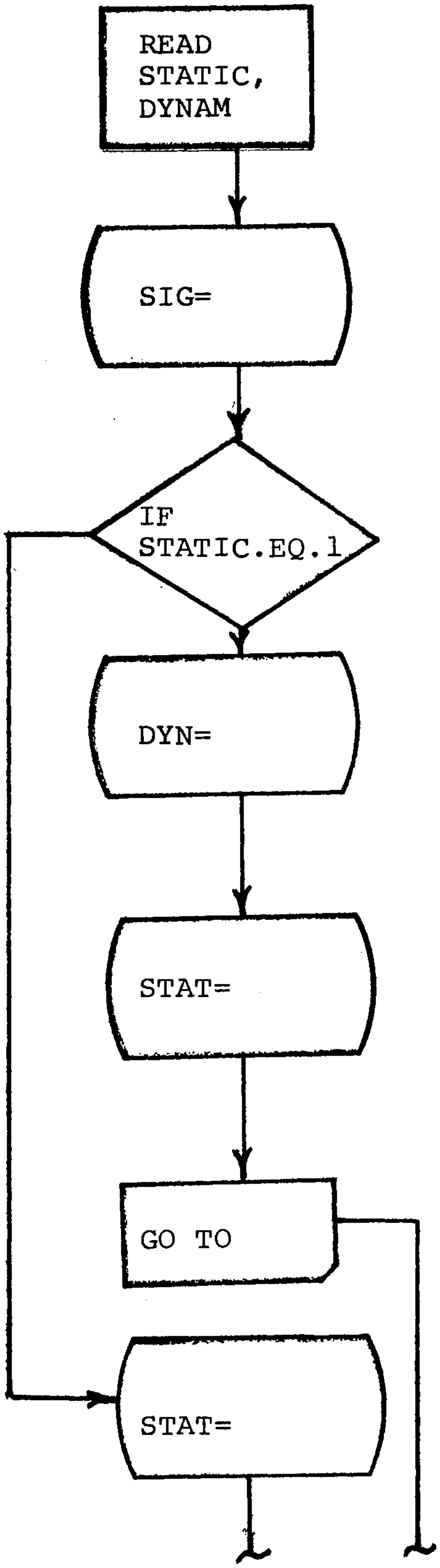

Determine the avaerage mission contribution of each subsystem

Determine the effectiveness of the given subsystem

Summation for effectiveness values

Determine the effectiveness of the system configuration

Return to the main program




Input the ranking of the static and dynamic elements

Establih baseline importance factor

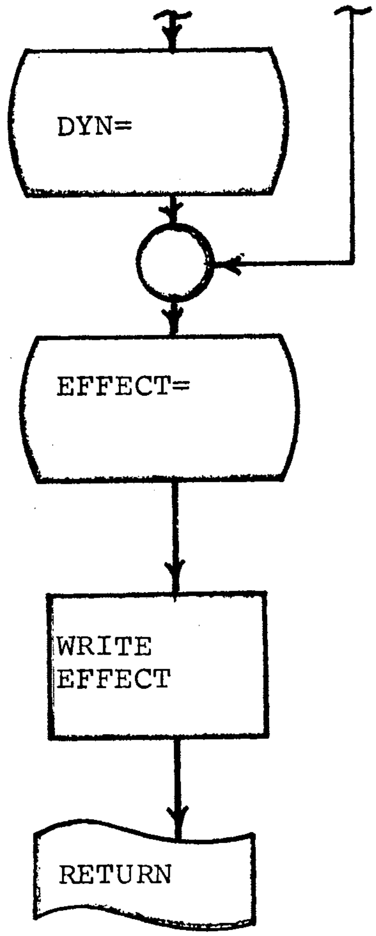
Establish the value of the static elements

Establish the value of the dynamic weighting factor

Establish the value of the static weighting factor

Transfer

Establish the value of the static weighting factor




Establish the value of the dynamic weighting factor

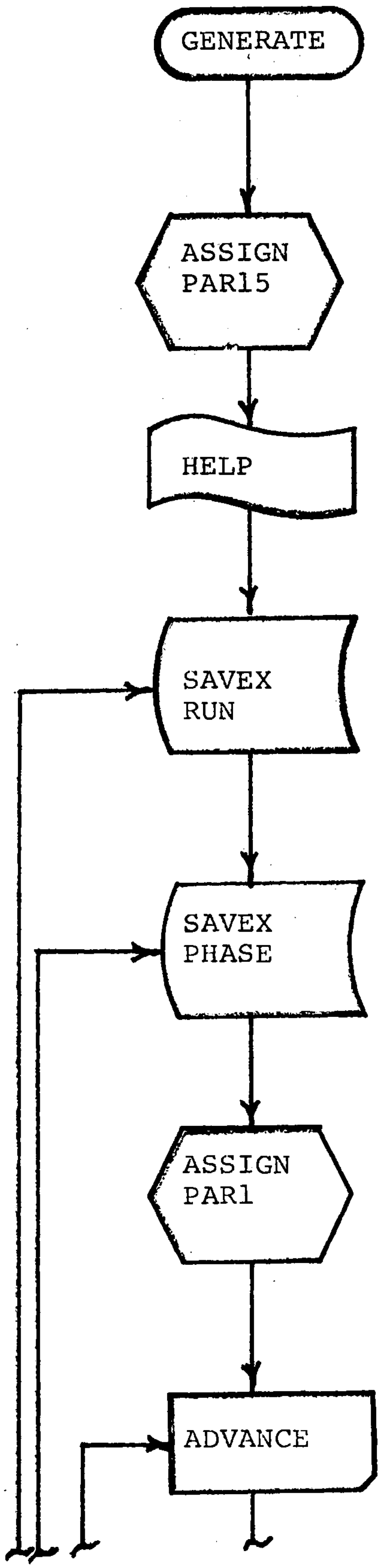
Determine the effectiveness of the given system configuration

Output the effectiveness of the system configuration

Return to the main program

FLOW CHART FOR THE GPSS SECTION

OF THE COMPUTER ROUTINE




Generate the time flow transactions

Assign to parameter 15 a code transfer symbol

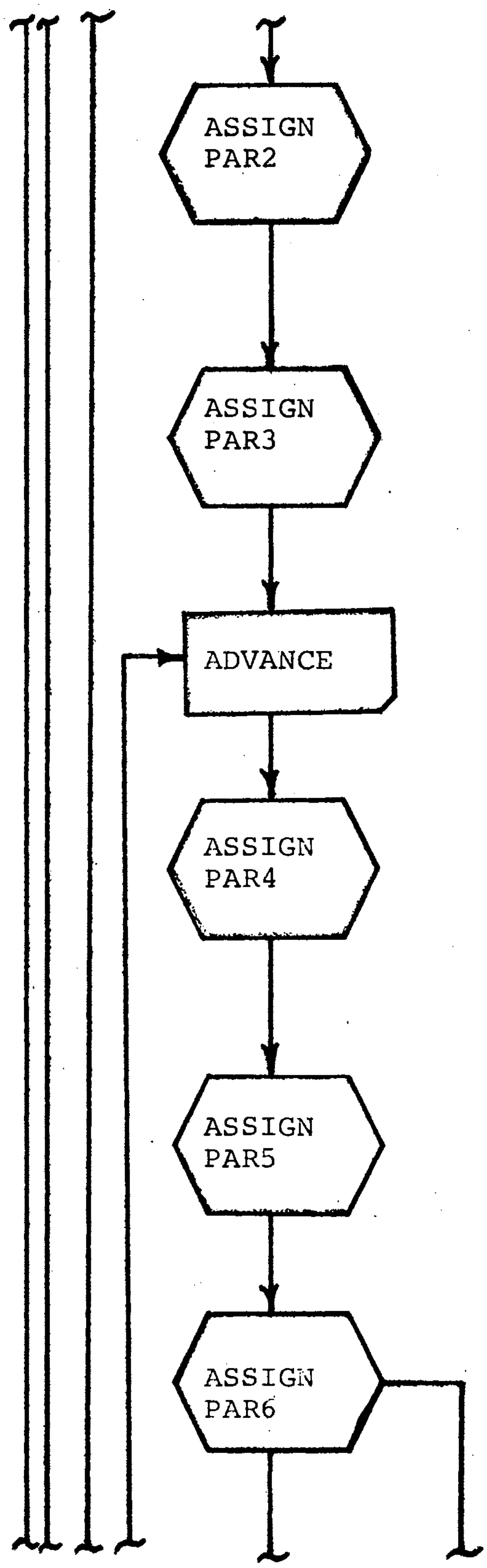
Transfer to the FORTRAN portion of the program

Increase the value of the savevalue RUN by 1

Increase the value of the savevalue PHASE by 1

Assign the number of subsystems to be evaluated to parameter 1

Loop return block




Assign the number of components in each subsystem to parameter 2

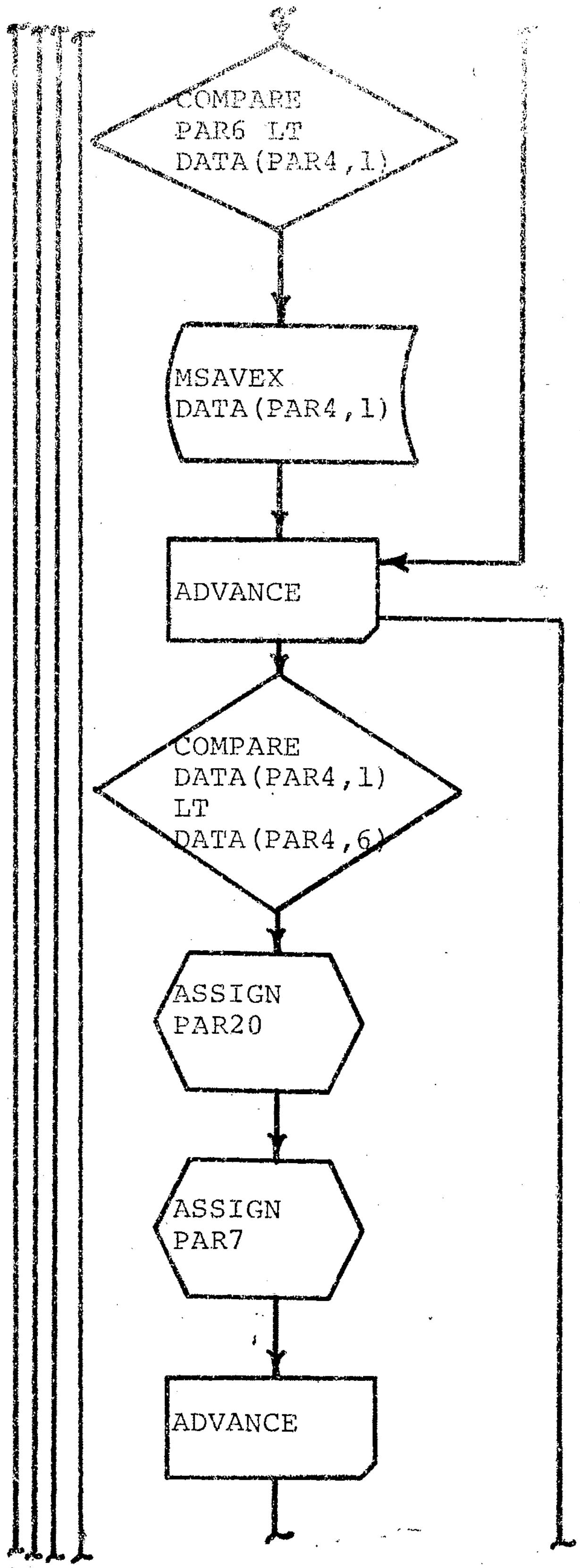
Assign the name of each subsystem to parameter 3

Loop return block

Assign the number of the component under analysis to parameter 4

Assign the name of the component under analysis to parameter 5

Assign the operational state of the component under analysis to parameter 6




Compare the present operational state of the component to the operational state in the last mission phase

Assign the new status of the component to DATA(PAR4,1)

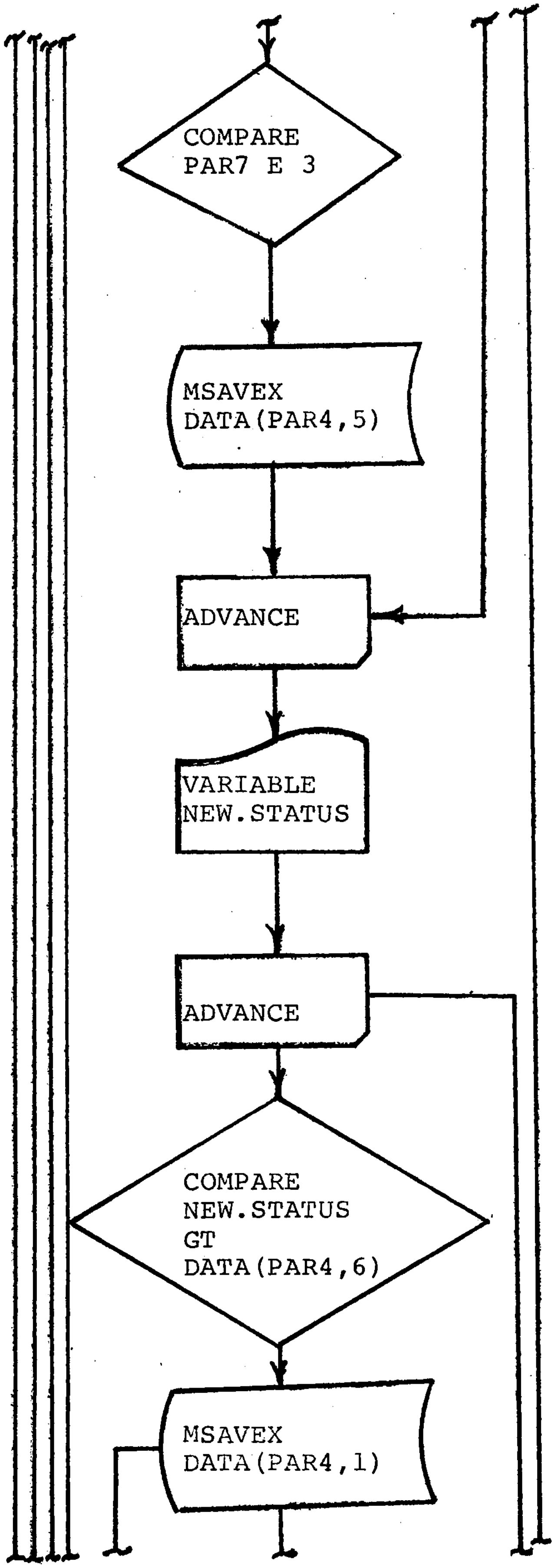
Conrol block

Compare the present operational state of the component to the fully operational state

Assign the design redundancy factor to parameter 20

Assign the new state of the redundant element to parameter 7

Control block




Compare the status of the redundant component to the operational state

Reduce the redundancy capability of the component

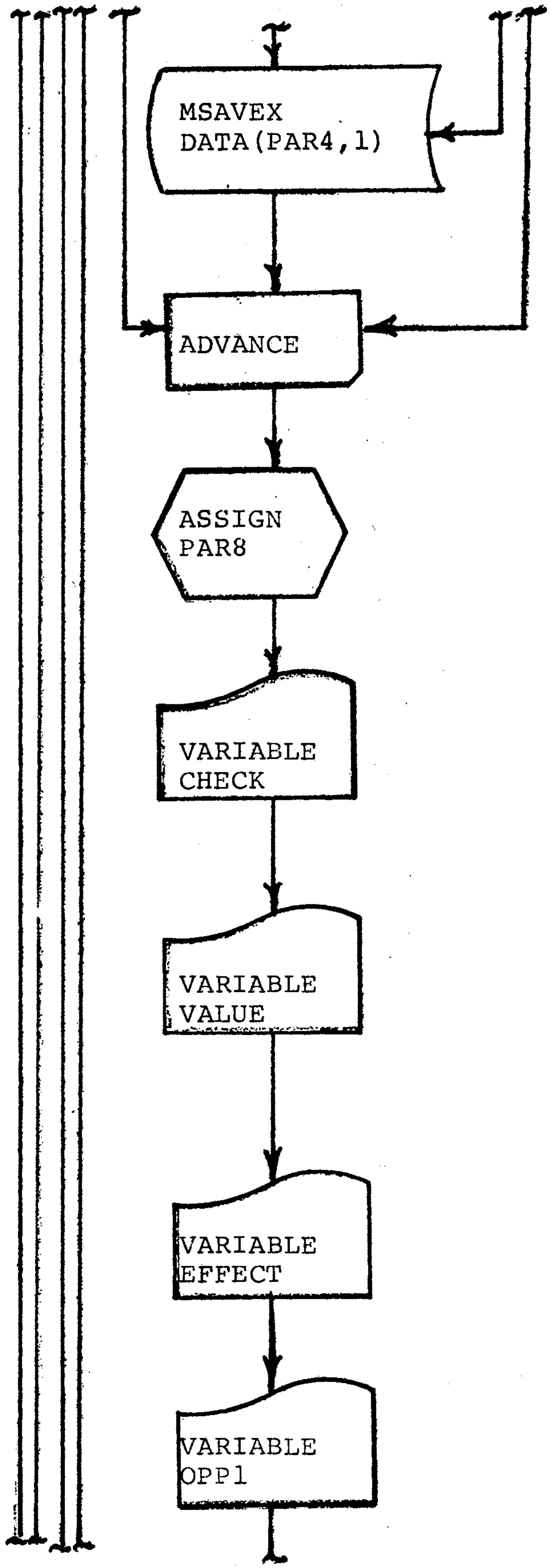
Loop return block

Determine the new operational status of the component

Control block

Compare the new status of the component to the fully operational state

Assign the new operational status of the component to the phase carrier




Assign the new status of the component to the phase carrier

Control block

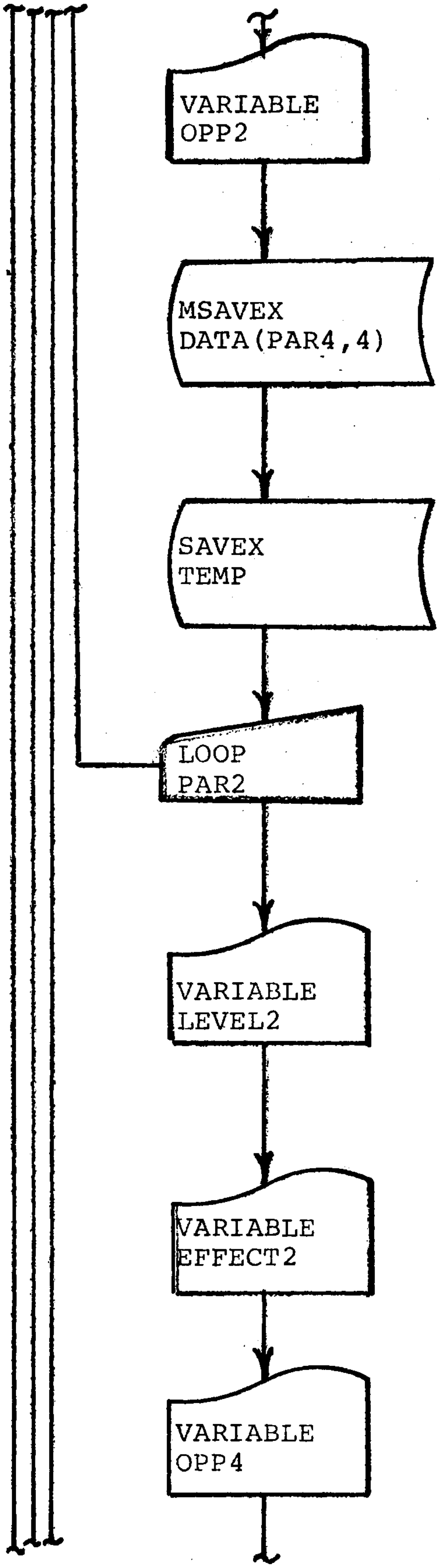
Assign the new status of the component to parameter 8

Calculate the interaction ratio for the component

Modify the operational status of the component to reflect the interaction ratio

Calculate the effectiveness of the component

Alter effectiveness value to baseline




Convert the effectiveness value to an integer

Assign the modified effectiveness value to savevalue DATA(PAR4,4)

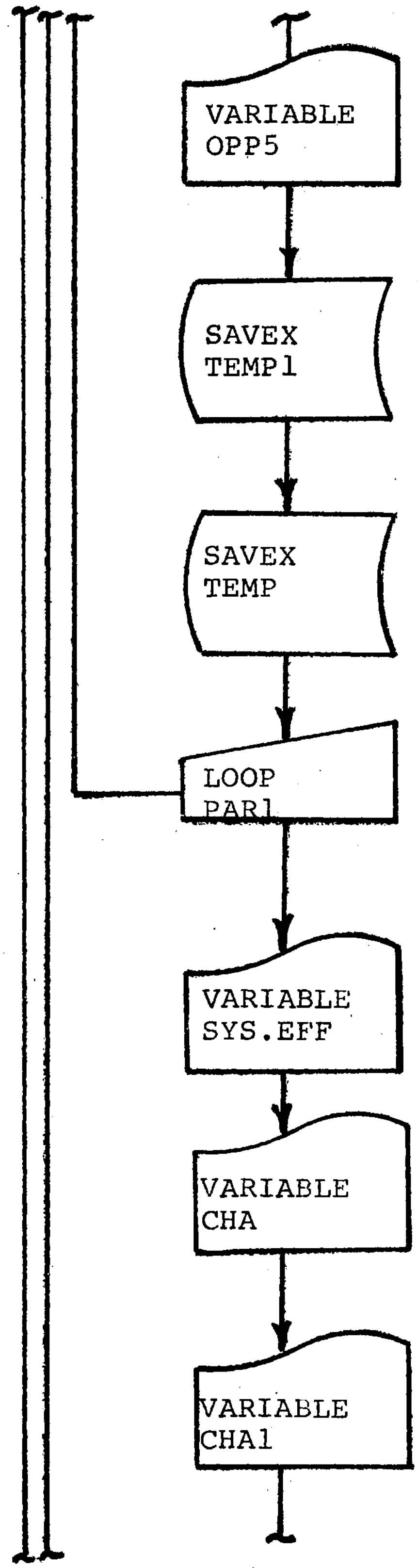
Sum the effectiveness values for the components in each subsystem

Loop for the number of components in each subsystem

Determine the average effectiveness value for the subsystem

Determine the effectiveness of each subsystem

Modify the effectiveness value




Convert the effectiveness value to an integer

Sum the effectiveness values for all subsystems

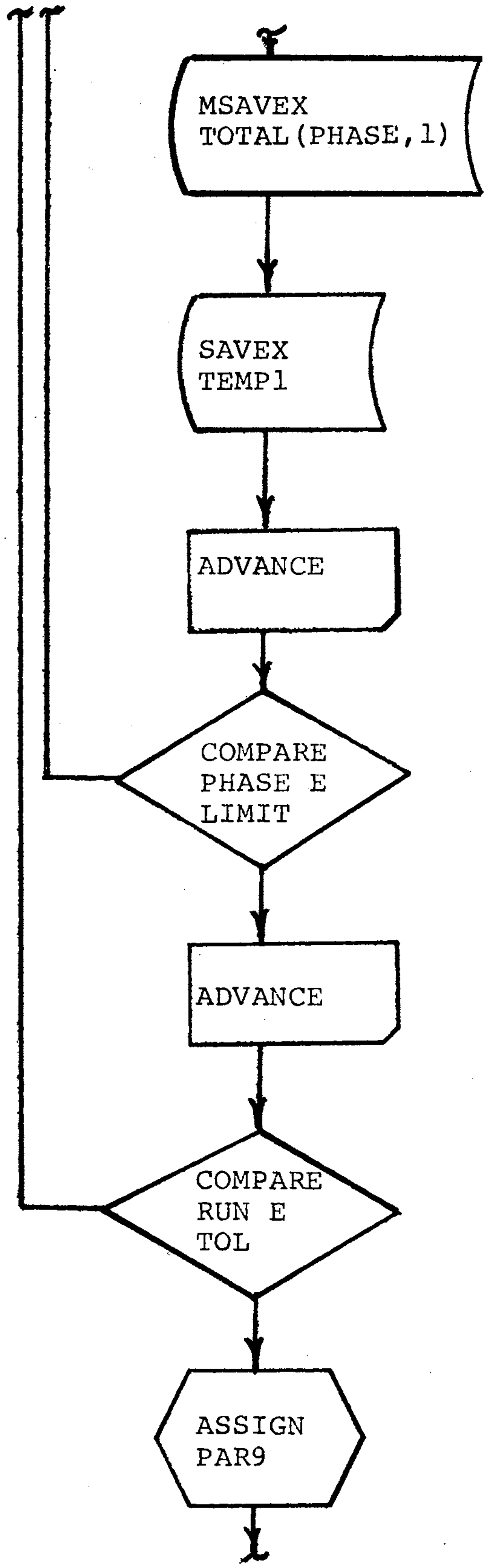
Reset savevalue TEMP to zero

Loop for the number of subsystems

Calculate the effectiveness for the system

Modify the effectiveness value

Convert the effectiveness value to an integer




Assign the effectiveness value for each mission phase

Reset the savevalue TEMP1 to zero

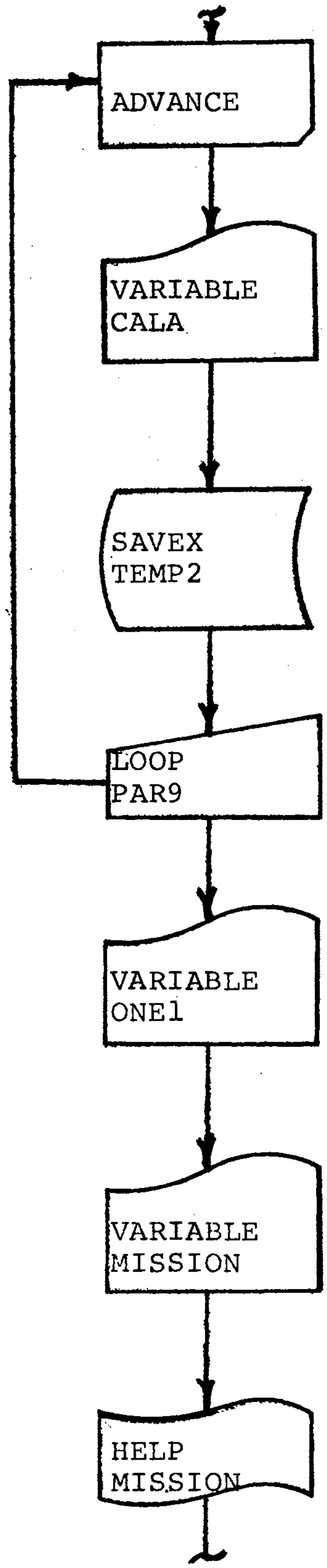
Control block

Determine if all of the mission phase have been simulated

Control block

Determine if all of the simulation runs have been completed

Assign the number of mission phase to be simulated to parameter 9




Loop return block

Calculate the total effectiveness for each mission phase

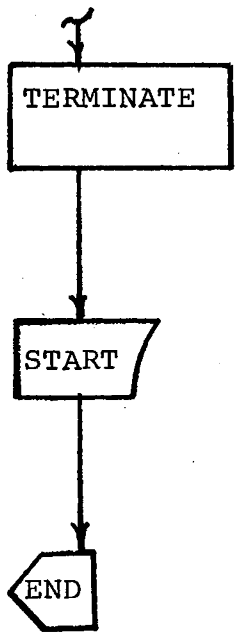
Sum the effectiveness for all phases

Loop for the number of mission phases

Calculate the base effectiveness for the system configuration

Modify the effectiveness value

Transfer to the FROTRAN portion of the program




Remove a transaction from the simulation process

Start X number of transactions

End the simulation

# APPENDIX B

# DETAILED DESCRIPTION OF THE SPACE TUG SYSTEM

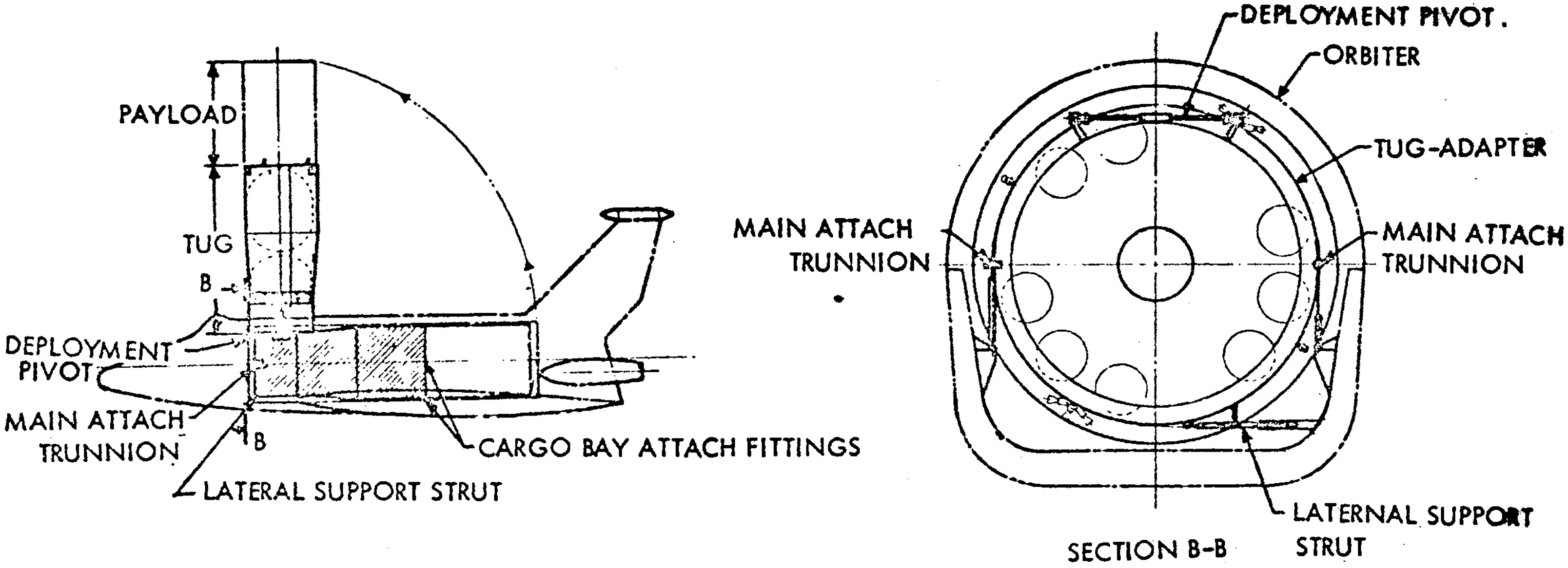



Figure 19. Space Tug Deployment Configuration

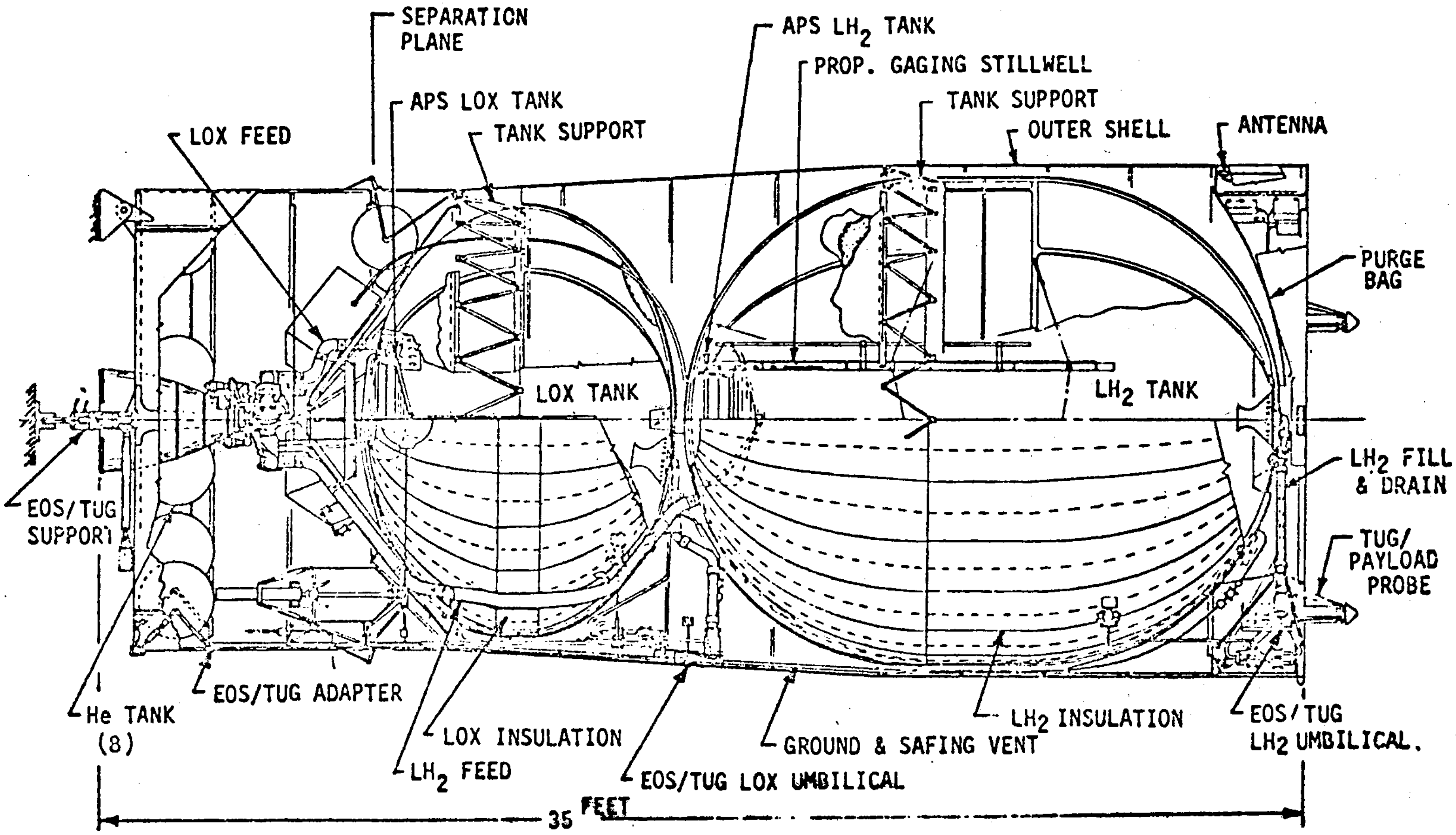



Figure 20. Space Tug Exposed Diagram

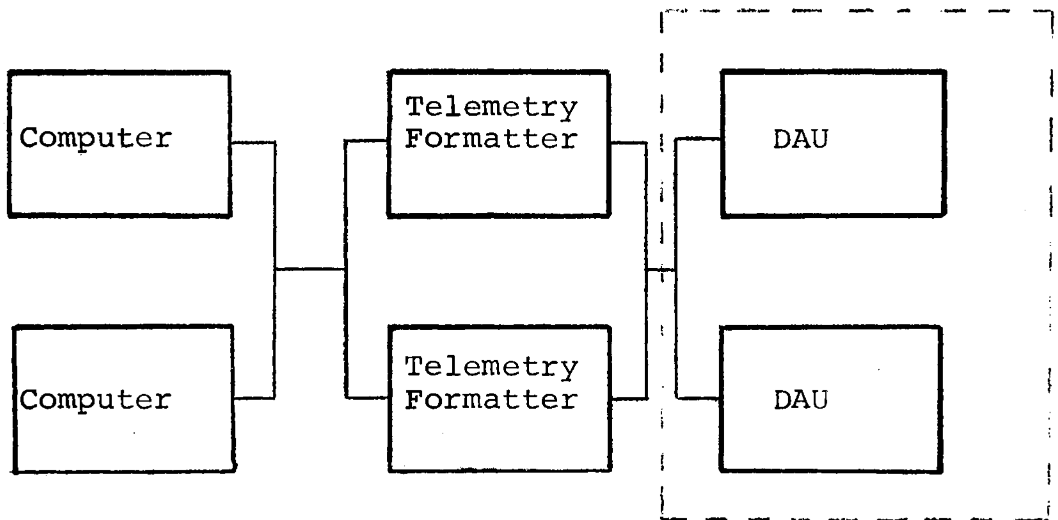



Figure 21. Data Management Block Diagram

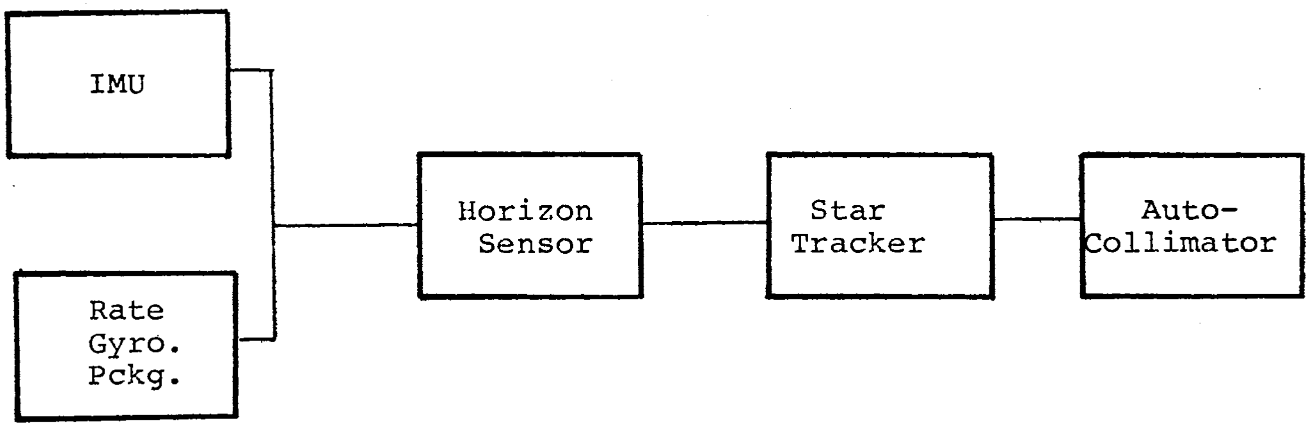



Figure 22. Guidance, Navigation and Control Block Diagram

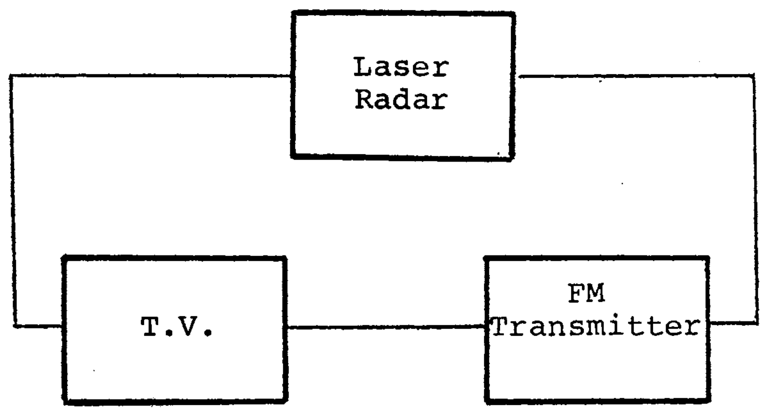



Figure 23. Docking Block Diagram

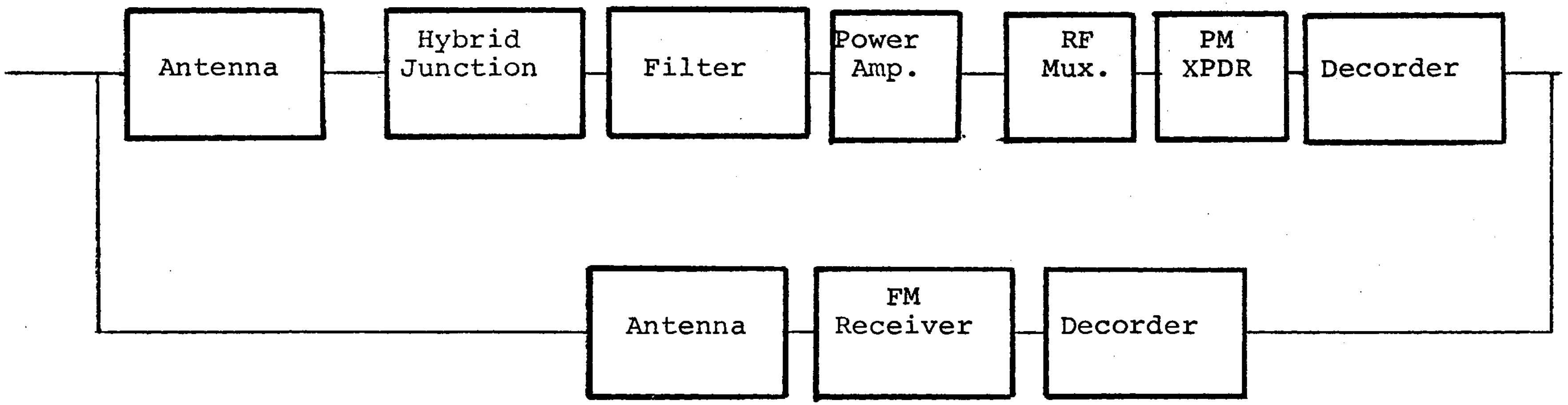


Figure 24. Communications Block Diagram

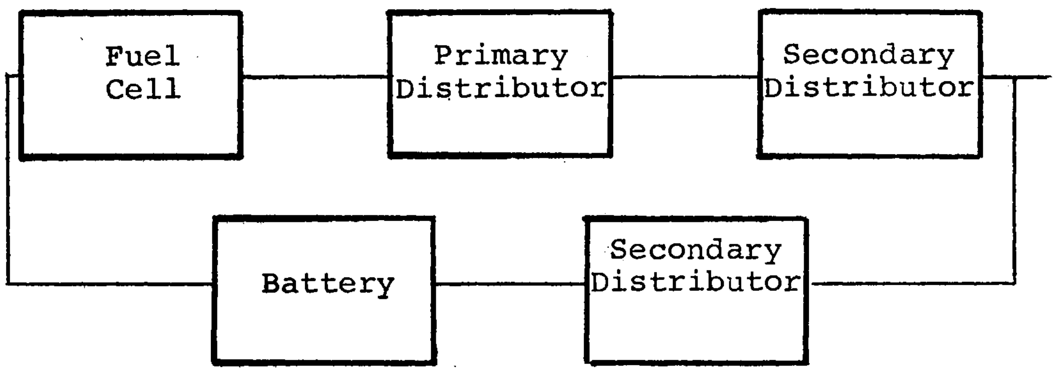



Figure 25. Power Generation Block Diagram

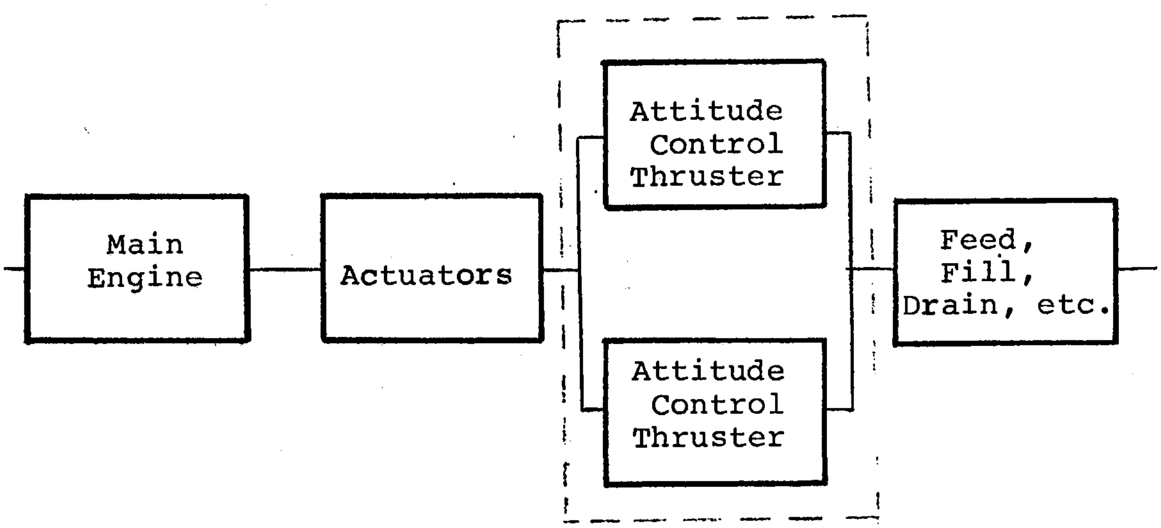



Figure 26. Propulsion Block Diagram

TABLE X

EXAMPLE OF PERFORMANCE CHARACTERISTIC DATA

| COMPONENT | QTY | UNIT WEIGHT | POWER WATTS 28VDC CONT | POWER WATTS 28VDC PEAK | KEY PERFORMANCE CHARACTERISTICS |
|---|---|---|---|---|---|
| DIGITAL COMPUTER | 2 | 26 | 60 | 60 | NO.SYSTEM: FIXED POINT<br>WORD LENGTH: 16 or 32 BITS<br>MEMORY SIZE: 64K - 16 BIT WORDS<br>MEMORY SPEED: 0.5 SEC CYCLE TIME<br>INSTRUCTIONS; 68 |

# APPENDIX C

# SYSTEM QUESTIONNAIRE

# SYSTEM QUESTIONNAIRE

Name of the System ________________________________

System Type:

___ Hardware ___ Hybrid

___ Software ___ Management

What is the primary mission of the system?

________________________________

________________________________

________________________________

________________________________

________________________________

What are the subobjectives which contribute to the primary mission?

1. ________________________________
2. ________________________________
3. ________________________________
4. ________________________________
5. ________________________________
6. ________________________________
7. ________________________________
8. ________________________________
9. ________________________________

If additional space is required, use the back of this page.

Rank the subojectives with respect to their contribution to the primary mission.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________

What parameters should be considered in evaluating mission success? Rank the importance of each parameter.

1. ______________________________ __________
2. ______________________________ __________
3. ______________________________ __________
4. ______________________________ __________
5. ______________________________ __________

What are the time phases involved in the mission to be performed?

1. ____________________________________________________________
2. ____________________________________________________________
3. ____________________________________________________________
4. ____________________________________________________________
5. ____________________________________________________________

What are the success limits for the system during each mission phase?

1. ______________________________

______________________________

2. ______________________________

______________________________

3. ______________________________

______________________________

4. ______________________________

______________________________

5. ______________________________

______________________________

What are the major subsystems of the system?

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________

Rank the major subsystems with respect to their mission importance.

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________
6. ____________________
7. ____________________
8. ____________________
9. ____________________

What are the operational limits on each subsystem?

1. ____________________

____________________

____________________

2. ____________________

____________________

____________________

3. ____________________

____________________

____________________

4. ____________________

____________________

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5. ____________________

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6. ______________________________________________

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7. ______________________________________________

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______________________________________________

8. ______________________________________________

______________________________________________

______________________________________________

9. ______________________________________________

______________________________________________

______________________________________________

The attached forms should be utilized for background analysis on all components.

COMPONENT PERFORMANCE LIMIT SUMMARY

| COMPONENT | QTY | PARAMETER VALUES | KEY PERFORMANCE CHARACTERISTICS |
|---|---|---|---|
| | | | |

## OPERATIONAL STATE ANALYSIS

| COMPONENT | NUMBER OF STATES | NAME AND RANK OF EACH OPERATIONAL STATE |
|---|---|---|
| | | |

VITA

Charles Clayton Daniel

Candidate for the Degree of

Doctor of Philosophy

Thesis: A GENERAL HYBRID MODEL FOR SYSTEM EFFECTIVENESS EVALUATIONS

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Professional Experience: Project control, management, evaluation of contract proposals, evaluation of hardware and software designs, the development of both general and special purpose software routines, the evaluation of system reliability activity, supervision of support personnel. NASA, 1968-72.